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BARRIERS TO ENERGY REDUCTION IN MANUFACTURING

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ABSTRACT

Sustainability has become an important part of the culture of most organisations, with shareholders and customers demanding that companies operate in an environmentally responsible way. This research focuses specifically on one aspect of industrial sustainability: energy reduction in manufacturing.

This research explores the management and organisational barriers within a manufacturing organisation, which prevent it from either implementing reductions in energy usage, or from realising the full benefit from them. The existence of these barriers is tested by collecting data on the perceptions of individuals within a UK facility belonging to a large aerospace manufacturing organisation, and by observing the progress of energy reduction projects in this facility. Data is collected through interview, questionnaire and by direct observation of the actors within this facility who are engaged in energy reduction activities.

Three case studies are presented focusing on projects to reduce the energy consumed by the surface treatment and machining of aluminium aircraft parts. Building from the literature, a list of twenty barriers to energy reduction is developed and illustrated through these case studies.

By analysing the narrative of these case studies it can be seen that these barriers are linked causally. This causality implies that a smaller number of key barriers will act as root causes of the larger list of barriers and is a main contribution of this work. The key barriers are found to be a **lack of accountability** and a **lack of ownership**.

The causality is exploited by proposing that interventions to overcome these key barriers will remove or diminish the effect of the other barriers. The first intervention proposed is that **objectives be set for Manufacturing Operations** to ensure that it is functionally accountable for its energy consumption. The second intervention is that **a focal point be nominated** to own the resulting activities and be given appropriate resources to meet the objectives.

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LIST OF ABBREVIATIONS

3BL	Triple Bottom Line
CO_2	Carbon Dioxide
CP	Cleaner Production
ESCO	Energy Service Company
GWh	gigawatt hours
IE	Industrial Ecology
kWh	kilowatt hours
LCM	Large Component Manufacturing
PP	Pollution Prevention
RQ	Research Question
VOC	Volatile Organic Compounds

1. INTRODUCTION

1.1. THE DRIVE FOR SUSTAINABLE MANUFACTURING

Manufacturers have always sought to produce more products using fewer resources in order to increase their bottom line by minimising waste. The same is true today. However an increasing number of manufacturers are beginning to see their bottom line not only in terms of financial gains, but also in relation to corporate responsibility. Manufacturers are seeking to operate in a sustainable way.

Energy is an important resource for manufacturers; it is the means by which raw materials can be transformed into useful products. Reducing energy consumption clearly has advantages for manufacturers, not only in terms of reduced operating cost but also in terms of the positive corporate image resulting from actively engaging in sustainable business.

Financial security and environmental stewardship go hand-in-hand for companies seeking to operate in a sustainable way. That is, sustainable companies are ones which seek to provide a benefit to society today without compromising their ability to continue to do so in the future – and funding those activities is as equally important as protecting the environment in which they operate and the society to which they provide their goods or services. Saving energy both makes good financial sense and is clearly something which any company seeking to be sustainable should do.

Thus in order to operate in a more sustainable way, many manufacturing organisations are starting to seek to reduce their energy consumption. Emerging technologies allow manufacturers to minimise energy consumption when specifying new production processes, however other than injecting technology into the shop floor most examples of improving existing systems are associated with improving the operation at a *facility* level - that is, manufacturers are improving the infrastructure which supports manufacturing operations without improving the manufacturing process itself.

There are many documented examples of continuous improvement of manufacturing processes using a variety of methods applied across many different organisations and industry sectors (see 2.3.2). Such examples show how the system has been improved with respect to lead times, cost of production, quality of products, and other traditional manufacturing metrics. There are few, if any, examples of improving the manufacturing process to become more energy efficient.

The benefits of reducing the energy consumption of manufacturing operations are clear. The increasing cost of energy is also a powerful driver even if for some manufacturers the pressure from customers to operate more sustainably is not. Yet there are few examples of manufacturers reducing energy consumption by improving their manufacturing processes. In the absence of any other explanation it is therefore proposed that barriers must exist to energy reduction in manufacturing.

Proposal: Barriers exist to energy reduction in manufacturing.

The purpose of this research is to uncover these barriers and by so doing propose ways in which they can be overcome.

1.2. DIRECTION OF THE RESEARCH

The focus of this enquiry will be on a UK manufacturing site belonging to a large European aerospace manufacturing organisation. The site is responsible for elementary part production as well as assembly of major component assemblies and thus the range of manufacturing processes is diverse. The enquiry will focus on manufacturing processes within the Large Component Manufacturing (LCM) part of the facility; this will be the **unit of analysis**.

In brief the processes within the unit of analysis are *machining*, *surface treatment* (including anodising and painting) and *forming* (including thermal and mechanical forming). Any activities and parts of the organisation which are involved in this process will be considered inside scope whether they are specialised for that area (e.g. Operations, Maintenance) or whether they are general support functions with a range of responsibilities outside that area (e.g. Manufacturing Engineering, Facility Management). Other parties external to the manufacturing organisation will be considered outside scope. This includes suppliers into LCM, subcontractors working within LCM and any other parties who are outside the direct control of management within the unit of analysis.

The manufacturing organisation has set challenging objectives for improvement across a number of environmental indicators. These include water (usage and discharge), waste, volatile organic compounds (VOCs), carbon dioxide (CO_2) and energy. With respect to energy, the target across its manufacturing plants is to achieve a 30% reduction by 2020 when compared to 2006 levels. It is expected that the majority of this target will be met by various actions of Facility Management - however 7 percentage points (or around a quarter of the total reduction) is expected to come from improvements made by Manufacturing Operations to the manufacturing processes.

As indicated, the focus of the research will be on energy reduction inside the unit of analysis as a means for the manufacturing organisation to operate in a more sustainable way. Reducing the energy used for producing products is often a quick and powerful way in which an organisation can have an impact on its performance. Energy consumption can also be measured through basic metering, making it a lot easier to measure than other sustainability indicators, such as emissions.

Energy is also an attractive place to start since it has a direct cost associated with it which is not insignificant and is rising over time. Thus in the traditional economics used by most organisations it may be possible to justify investment based on financial payback alone. It is also linked to CO_2 emissions which means that by reducing energy a manufacturer can decrease both cost and environmental impact simultaneously.

At the start of the enquiry there was limited evidence of any energy reduction within a manufacturing perimeter across the manufacturing organisation. It was postulated that this may be due to barriers which exist within the organisation. An improvement initiative was started focusing on one aspect of the unit of analysis and thus it was agreed that this enquiry would seek to determine the existence and extent of any barriers by observing attempts to reduce energy within the unit of analysis.

1.2.1. Research Questions

The direction of the research is best described as discrete objectives in the form of questions - that is, as **research questions**. These questions help to define and drive the research agenda and provide a reference point for the researcher throughout the course of an enquiry. The objectives of this research can thus be described as shown below.

The first research question should be related to the identification of the barriers which are expected to exist within the unit of analysis, since this is the core part of the research and will validate the Proposal given in 1.1.

> *RQ1: What are the management and organisational barriers to the implementation of energy reduction initiatives?*

The second research question should build on this and direct the research to provide a real benefit to practice. That is, as well as identifying what barriers exist, the research should also provide some direction in terms of how these barriers may be overcome.

> *RQ2: What management or organisational interventions can be made to overcome these barriers?*

These questions reflect the direction of the research and provide a basis from which to develop the research further.

1.2.2. Contribution

In the world of practice, the success of a project is determined by the extent to which it helps a practitioner do what it does better. For a manufacturing organisation (and indeed any other business) a good measure of success will be impact on the bottom line, and for an improvement project this can be measured as a financial saving (or avoidance of cost) or as an increase in revenue (or increase in sales/profit). For an organisation concerned with sustainability and carrying out energy reduction activities, the contribution of a research project can thus be measured in a very objective way as the absolute energy saving as a result of the research activities. Another less objective measure is the extent to which the research contributes to practice, perhaps through the introduction of new methods or tools.

The ultimate measure of successful research is the extent to which it contributes to knowledge - that is, what do we now know that we did not know before the enquiry was carried out. The research questions should point towards new knowledge and help the researcher to describe something about the unit of analysis which was not known before. In the case of this enquiry the contribution will therefore be an understanding of what is currently blocking progress in energy reduction (in the unit of analysis), and a recommendation of the means to overcome these barriers.

To begin with a researcher must therefore understand what is currently known, both within the unit of analysis and more widely in related areas. This understanding is gained by carrying out a Literature Review, which is the subject of the following chapter.

1.4. THESIS STRUCTURE

This thesis is structured across six chapters as described below.

The **Introduction** sets the scene for the research by providing background information on the area of interest, defining the direction of the research by describing the unit of analysis and proposing two research questions which will form the basis of the enquiry.

The research questions are confirmed through the **Literature Review**, through which the current knowledge in this area is described as well as gaps in this knowledge.

The philosophical standpoint of the researcher and the approach adopted in the enquiry is discussed in the **Methodology** chapter, including an outline of the research plan and the specific tools the researcher will apply in the enquiry.

The information collected within the unit of analysis by applying the methodology is presented in the **Data Collection** chapter, through which an answer can be seen to emerge for the first research question.

The data is further analysed in the **Data Analysis** chapter where patterns in the data are identified and both research questions can be answered more fully, showing the generation of new knowledge.

This new knowledge is then explored and discussed in the **Discussion and Conclusion**, the contribution of the research stated and any further work outlined.

2. LITERATURE REVIEW

The primary purpose of a literature review is to uncover existing knowledge. This provides a researcher with a solid foundation for their enquiry, whatever form it takes, by ensuring that any theory built or tested throughout the enquiry adds to knowledge.

This literature review has been conducted against the research questions defined in 1.2.1. The following will therefore explore the current answers to these questions in the literature, identify any gaps in the literature and use these gaps to provide a clear definition to the subsequent enquiry.

In order to uncover existing knowledge relevant to the field of enquiry it is important that the initial search is focused in the right place. The following section (2.1) describes how keywords were selected based on the research questions and the manner in which they were used to search through literature databases in an iterative manner. Following this the themes identified in the literature are presented and discussed (2.2, 2.3) which provides the foundation for the enquiry by identifying gaps in current knowledge (2.4).

2.1. ACCESSING THE LITERATURE

2.1.1. Keywords

Initially, the literature was accessed by means of a series of keyword searches on a number of academic databases. In order to focus on papers containing information specifically relating to *energy reduction*, all searches contained the search term (energy) in Boolean AND, rather than a more general (sustainab*) search term.

For the initial searches to provide the focus on *manufacturing* papers the following key words were used:

(manufactur OR industr* OR operations OR production)*

To further narrow the focus on the *implementation* of energy saving practices, the term (implement*) was used in Boolean AND. Thus the initial search term was:

TITLE = (energy) AND (manufactur OR industr* OR operations OR production) AND (implement*)*

Based on the initial results, a set of enhanced keywords were used, where (implement*) was replaced with explicit or implicit keywords from the returned papers, such as the following:

("energy efficiency gap")
(measur AND "energy efficiency")*
((improv OR optimi* OR kaizen) AND energy)*
(energy AND saving)
((driv OR enabl* OR barrie*) AND energy)*

From these initial searches there was found to be a lack of papers dealing with the way energy saving practices were introduced. Thus a further set of keywords was developed, again replacing the (implement*) search term:

(method)*
(approach)*
(deploy)*
(lean)

The keywords used reflected the content of the research questions and are focused on implementing **energy reductions** in a **manufacturing** environment. A strict exclusion policy was employed such that only papers whose abstracts showed a clear alignment to the research questions were used.

2.1.2. Databases

Searches were conducted using the database search engines available through the Cranfield University library, such as ProQuest, EBSCO, Scopus and ISI Web of Knowledge. These databases were also supplemented by the use of Google Scholar.

Of the databases used, **Scopus** was found to be the best source of information. **EBSCO** and **ISI Web of Knowledge** were also considered to contain some useful information. **ProQuest** was excluded from the later searches since initial searches returned mainly irrelevant articles predominantly non-scholarly in nature. **Google Scholar** was only used to retrieve papers which were not retrievable from other sources – that is, it was only used to locate and download specific named papers rather than for key word searches, since the application of search terms through Google is not as strictly controllable.

2.1.3. Iterative Approach in the Literature Search

The articles retrieved initially provided access to a much richer body of knowledge by:

- Identifying citations of previous work
- Identifying key authors in the field
- Identifying key journals and conferences in the field
- Providing new keywords to create additional database searches

The body of knowledge identified through the literature review thus grew with each article found. This snowball effect alone is not sufficient to identify all the key papers, and is heavily dependent upon the initial keywords used. Thus in addition to this approach regular reviews were conducted with other researchers in this field. As a result of these reviews, and by relaxing the strict focus on energy reduction in manufacturing, complementary knowledge was also explored on **sustainability** in general and on **organisational change**.

A total of 82 papers were found which were believed to have content relevant to this enquiry. (The total including rejected papers was not recorded.) These papers were further reviewed and the most useful of these are discussed in the following section and existing knowledge presented through the themes identified.

2.2. TOWARDS A LIST OF BARRIERS

In order to gain an understanding of the field of the enquiry a brief introduction is given to sustainable production and its development over the past half century based on the literature, with a particular focus on energy reduction in manufacturing. In order to answer the first research question on what the barriers are in this field, the following sections then go on to present existing knowledge on barriers with the aim of producing a list of barriers to manufacturing energy reduction based on the literature.

2.2.1. Drivers for Energy Saving: From Cost Reduction to Sustainable Production

The Industrial Revolution was driven by the consumption of fossil fuels and the availability of relatively cheap energy. It perhaps was not until the oil crises of the 1970s that manufacturers started to think about their energy consumption, and how by reducing energy usage they could provide security to their on-going operations and reduce their operating costs. Although organisations were becoming more environmentally aware through the 70s and 80s, the literature of the time reflects the strong emphasis on the *cost* benefits achieved through energy reduction over everything else (Boatfield, 1984).

To work in a *sustainable* way means *to meet current needs without compromising the ability to meet future needs* (WCED, 1987). From a general business viewpoint this means being able to operate both now and in the future. Obviously to be able to do so businesses must make money – even non-profit organisations need to fund their on-going activities – but it would be naïve to assume that sustainability was about cash flow alone. A useful principle which many corporations have adopted when reporting their sustainability efforts is that of a *triple bottom line* (3BL), which not only incorporates the economic elements of sustainability, but also environmental and social factors (Elkington, 1997).

There is a growing body of knowledge on sustainable manufacturing. Approaches such as Industrial Ecology (IE) look at how the industrial sector can continue to meet its fundamental needs by behaving more like a natural system; that is, IE examines how industrial resources can be used in a more sustainable way (Erkman, 1997). Other approaches such as Cleaner Production (CP) are more focused on how individual organisations can minimise their impact, having evolved from simple 'end of pipe' solutions towards Pollution Prevention (PP) approaches to sustainability (Berkel, Willems, & Lafleur, 1997).

The focus on resource flows in IE is particularly interesting. If one considers a natural system it can be seen that all resource flows are *closed loop*; that is, nothing is wasted in a natural system, and the 'waste' from one natural process becomes the 'food' for another natural process (McDonough & Braungart, 2002). Material is constantly reused in a natural system, and thus in an industrial system proponents of IE would seek to reuse as much material as possible.

Energy is obviously another important industrial resource, and the reduction of energy usage in manufacturing is a key goal for any company which wishes to act in a sustainable way. However most examples in the IE and CP literature focus on *material* resources with energy reduction forming a part of *emissions* reduction rather than a goal in itself. From an IE perspective this is perhaps unsurprising; in a natural system the only input is energy (usually as sunlight), which is in abundant supply. Indeed one could argue that a sustainable organisation would be less concerned with reducing energy than changing the source of that energy. However this ignores the impact that energy consumption currently has in most manufacturing organisations: the

depletion of finite natural resources, and the emission of gases which contribute to climate change.

The majority of contemporary literature on manufacturing energy reduction does not focus on these environmental impacts. Where cases are presented showing energy savings they are usually quantified in terms of a cost reduction rather than, for example, the avoidance of the emission of CO_2. Compared with the reduction of other manufacturing resources shown in the IE and CP literature where there is an increasing tendency to report impact across a 3BL, the literature on energy reduction could be considered immature.

This could of course be a reflection of the thinking within manufacturing organisations rather than the analysis by researchers. Although there are reasons why companies would want to save energy across all three elements of the 3BL, evidence indicates that the main driver remains cost reduction (de Groot, 2001; Thollander & Ottosson, 2007). Indeed even governmental policy on energy efficiency tends to focus on the economic aspects (e.g. EC directive 2006/32/EC (2006), UK Energy Bill (2012)). When describing the barriers to energy reduction encountered in the literature, looking at the economic barriers is therefore an appropriate place to start.

2.2.2. Economic Barriers to Energy Reduction

De Canio (1993) uses economic theory to describe the reasons organisations seem unwilling to invest in energy reduction projects, even when it would make economic sense to do so. Jaffe and Stavins (1994) build on this work, describing the barriers to energy reduction in terms of failures in the *market* (for energy reducing technologies, for example), and other economic failures not linked with the market (such as risk aversion). The result of these barriers preventing an organisation from operating at its hypothetical potential level of energy efficiency is described as an "energy-efficiency gap". This is best described using Jaffe and Stavins' own diagram (Figure 1).

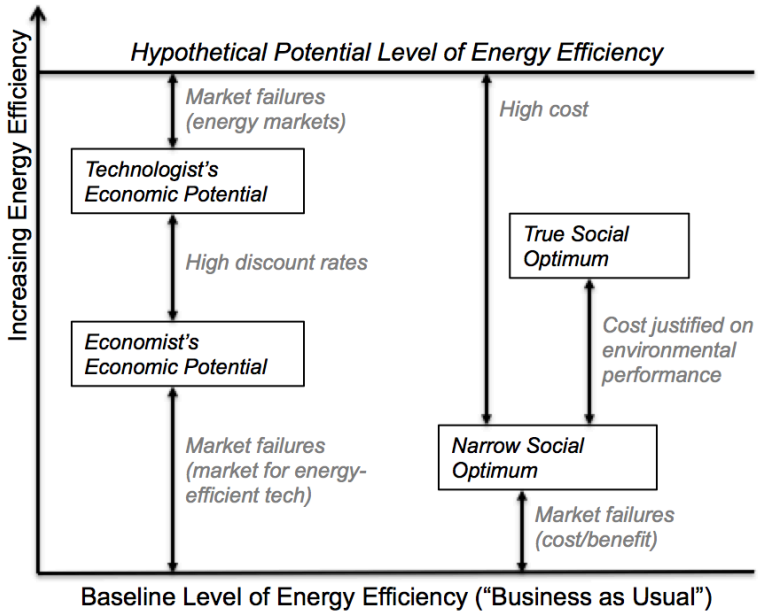

Figure 1- Energy Efficiency Gaps (based on Jaffe & Stavins, 1994)

Here different energy efficiency paradigms are shown on a scale between the business-as-usual paradigm and the hypothetical potential (based on available technology). The barriers which need to be overcome when moving from one paradigm to another are identifiable next to each of the "gaps", and can be broadly categorised as market failures or non-market failures, as briefly mentioned above. (Here we can take 'market' to mean any situation in which there are customers and suppliers, such as within a manufacturing organisation.)

Market failures relate to the asymmetry or imperfection of information between various parties wishing to operate within that market. A common example of market failure is that of the principal-agent problem, which is classically described as the tension between shareholders (principal) and directors (agent) who may have differing views on what actions are in the best interest of a company. De Canio builds on this definition and he and subsequent authors use the term more generically to describe when the actions of a *principal* (e.g. a manufacturing operations manager) and an *agent* (e.g. a facilities manager) have motivations which are not aligned towards the same optimum situation, which leads to *split incentives* and *adverse selection*. For example:

An operations manager (the principal) requires a facility in which to conduct manufacturing operations and makes a request of the facilities manager (the agent) to provide this. The operations manager wants the facility to be cheap to run. However the facilities manager wants the facility to be of minimum capital outlay. If the facilities manager provides a building that is cheap to run it is unlikely that he will meet his objective of a building that is cheap to purchase, and it is unlikely that he will be able to recover the benefits of providing a more efficient building.

Non-market failures generally relate to individuals responding to perceived uncertainty by choosing not to invest. This uncertainty can relate to a lack of confidence in the improvement itself, the claimed benefits from an improvement or the appropriateness of the improvement in a given situation. Linked to this is the idea of organisational *inertia*, where business-as-usual is considered more favourable than the unknown.

The approaches outlined by de Canio and Jaffe & Stavins are very firmly grounded in economic theory and perhaps are rightly suited to analysing barriers to energy reduction given the emphasis manufacturing organisations place on economic measures. However it is also evident that there are clear *social* aspects to investment decisions, particularly when considering the bounded rationality of individuals operating within an organisation. It would therefore be appropriate to also consider barriers from a social perspective.

2.2.4. Barriers from the Energy Efficiency Literature

In order to provide a basis for development of barriers specific to the *implementation* of energy efficiency initiatives, the literature on change management was briefly reviewed. This literature describes four critical factors which can either be barriers or drivers for effective change (from Senior (2002), who cites multiple corroborating sources):

- **Politics** – governmental action, such as legislation or incentives, can influence change
- **Economics** – the availability of funds and willingness to invest those funds can influence what is a priority for change
- **Social** factors – the behaviour of individuals and the structure of an organisation can have an impact on the ability to change
- **Technology** – the introduction (or absence) of a new technology can be a catalyst (or blocker) for change

This is often referred to by the acronym **PEST**, although there are many variations (Senior, 2002). Indeed there are also variations which seek to encompass additional factors, such as **legal** and **environmental** (making the acronym PESTLE), **ethical** (resulting in STEEPLE), amongst others.

Weber (1997), writing on energy efficiency, broadly agrees with PEST as a set of top level barriers. However he believes that technological considerations will permeate through any decision and does not consider it a class of barrier in itself; the barriers described are between the current state and the *technical* optimum rather than some other *ideal* situation. He describes the political barriers as *institutional* barriers, indicating that it is not governments alone that can exert political forces for or against change. His economic barriers encompass the market failures of de Canio, however he believes that non-market failures included by Jaffe and Stavins are more social in nature than economic. Weber also makes the distinction between the behavioural side of social barriers and the organisational side; organisational barriers occur within a company, whereas behavioural barriers occur within an individual.

The distinction between behavioural and organisational barriers is shared by Sorrell et al. (2000) who provide a taxonomy of barriers building on the foundations laid by Jaffe and Stavins and de Canio. As with Weber, Sorrell accepts that there will always be technical limitations to the degree to which an organisation can reduce its energy consumption, and so does not include technology as a barrier *per se*. The premise of Sorrell's research is that policy can be an enabler to greater energy efficiency, and the purpose of his work is to identify appropriate policy instruments which overcome the barriers to energy reduction. It is not surprising therefore that he excludes political barriers from his categorisation. The barriers he describes can be broadly categorised as follows:

- **Economic** – as with Weber, these are seen as being market failures (see 2.2.2 above). Many other authors also believe that these can be overcome by appropriate national and international policy (Jaffe & Stavins, 1994; Rohdin & Thollander, 2006; Weber, 1997).
- **Organisational** – describing some of the non-market failures from Jaffe & Stavins, in particular the importance of the quality of information used to make decisions, and the occasional conflicts of interests that occur within organisations.
- **Behavioural** – where the limitations of human decision making affect the implementation of energy reduction projects, such as bounded rationality (the limited ability of rational people to process large amounts of information in a completely rational way), risk avoidance and personal values and beliefs.

The fifteen barriers described in Sorrell's taxonomy are shown below (Table 1).

Table 1 - Barriers to Energy-Efficiency (based on Sorrell et al., 2000)

Economic		Behavioural	Organisational Theory
Non-Market Failures	Market Failures		
Heterogeneity	Imperfect information	Bounded rationality	Power
Hidden costs	Split incentives	Form of information	Culture
Access to capital	Adverse selection	Credibility and trust	
Risk	Principal-agent relationships	Inertia	
		Values	

These barriers have been used in some form by numerous authors (Palm, 2009; Rohdin & Thollander, 2006; Thollander & Ottosson, 2007). Some authors (e.g. Aflaki & Kleindorfer, 2010; Rohdin & Thollander, 2006) have their own list of barriers, but it is clear that these barriers can fit inside this framework. Rohdin and Thollander (2006), for example, use their own list of barriers to conduct a survey, but then align the results to the theoretical framework above.

This list of barriers provides an appropriate summary of the barriers from the literature discussed so far both from an economic and organisational change perspective. Its use by a number of later authors gives the list a degree of credibility and also shows how it can be used for assessing barriers across different organisations. **For this reason this list was taken forward and formed the foundation of additional stages of the enquiry**, particularly the questionnaire (see 4.3).

2.3. THEMES IN THE LITERATURE

2.3.1. Importance of the Barriers

Sorrell investigated the existence and importance of barriers in three very different sectors, the most relevant to manufacturing being that which he termed 'mechanical engineering' (Sorrell et al., 2000). (The other sectors were higher education and brewing.) By interviewing energy managers in this sector across the UK, Germany and Ireland, he found that the most significant barriers were *economic*; specifically, energy managers at the companies investigated claimed that **accessing capital** was difficult, and that even when capital was available it was difficult to overcome the perception of **hidden costs** associated with implementing an improvement. However, he also found that the function responsible for energy tended to have a low status, particularly when compared with activities considered to be core to the business. Thus a **lack of power** of individuals was also important and was expressed as an *organisational* barrier.

The same model was used in more recent research into the perception of these barriers in non-energy intensive (Rohdin & Thollander, 2006) and energy-intensive (Thollander & Ottosson, 2007) industries in Sweden. The research has shown that the most significant barriers are related to the perceived **risk** of stopping production, either deliberately (e.g. to install new equipment) or accidentally (e.g. through incorrect implementation of an energy-saving investment), and the subsequent cost that would incur. As with Sorrell, these barriers are also related to **hidden costs**.

It would seem from this research that the *economic* barriers are the most significant blockers to energy reduction, at least in terms of the perceived importance. Palm and Thollander (2010) conduct a similar review of that in Rohdin & Thollander and Thollander & Ottosson, coming to similar conclusions about economic barriers, and also identifying the importance of the barrier of a **lack of time** given to energy reduction activities (which Rohdin & Thollander categorise as a dimension of hidden cost). Palm also brings her expertise in the social aspects of energy saving (Palm, 2009) and describes how the *perception* of the importance of barriers is naturally taken in a *social* context. Thus when an energy manager implies that hidden costs are the biggest barrier to energy saving in his company, a form of non-market failure described in Jaffe & Stavins, the *cause* of this barrier may actually be due to the *values* of the individual and the *culture* of the organisation. The implication is that any barrier, other than perhaps market failures (and of course the technical and political barriers discussed previously), can be overcome through an organisational intervention. She describes examples of these in her paper with Thollander (Palm & Thollander, 2010).

The majority of the barriers in literature discussed so far are economic in nature. However significant organisational barriers have also been uncovered. Given that the importance of even the economic barriers is perceived in a social context (Palm & Thollander, 2010), it would not be unreasonable to assume that the importance of barriers is highly dependent upon personal observation and the organisational setting. Whilst the evidence suggests that economic barriers are the most important, the literature is not broad or detailed enough to assume universal validity. Indeed the literature focuses mainly on the perception of energy managers, and the evidence spans a small number of organisations. **Additional work is therefore required to validate the existence of the barriers outlined in the literature and assess their importance in a social context (their perception) in the unit of analysis.**

2.3.2. Overcoming Barriers: How has energy reduction been implemented effectively?

The literature provides some background on what the *problems* are when it comes to energy efficiency, but examples of what the *solutions* are are not often provided. Specific interventions are not clearly described in the literature. Some authors (de Groot, 2001; Palm & Thollander, 2010; Rohdin & Thollander, 2006; Thollander & Ottosson, 2007) describe what they consider to be motivations or drivers for reducing energy, but do not identify specific actions on how to reduce energy. These authors tend to use the description of the drivers to build a case for a political intervention, particularly in the case of overcoming market failures. The drivers taken from the body of knowledge on energy initiatives in Sweden's industrial sector (Rohdin & Thollander, 2006; Thollander & Ottosson, 2007), as well as other sources (de Groot, 2001) are described below.

- **Market-related driving forces** – such as reducing operating costs by reducing energy consumption, the threat of increasing energy prices, competition and opportunities provided by the suppliers of energy-efficiency products or services.
- **Political driving forces** – such as incentives and taxation. Some authors (e.g. Thollander & Ottosson, 2007) provide a more substantial description of specific policy instruments.
- **Behavioural driving forces** – such as the ambition and dedication of individuals, perhaps based on their sympathetic values towards energy reduction.
- **Organisational driving forces** – such as the increasing importance of a green corporate image, or the implementation of a long-term energy or environmental strategy.

From the discussion in Thollander and Ottosson (2007) a list of ten drivers for energy efficiency can be distilled. These are shown in Table 2 below and will be used during data collection (see 4.4) to provide a different perspective to Sorrell's barriers (from Table 1 above), which Thollander & Ottosson also use.

Table 2 - Drivers for energy efficiency (after Thollander & Ottosson, 2007)

Drivers	
Cost reduction	Personal commitment
Rising energy prices	Ambitious people
Competition	Long term energy strategy
Use of energy service companies (ESCOs)	Environmental management system
Green image	Improved working conditions

Although the categorisation of the drivers parallels that of the barriers, it is difficult to see a one-to-one relationship between the drivers and barriers; the drivers cannot be considered interventions for specific barriers. It is also unclear if there is a one-to-many relationship. For example, the acknowledgement that cost reduction through energy reduction is a significant driver for manufacturers does not itself overcome any of the economic barriers. Indeed it is the barriers which provide more information about the nature of an intervention than the driver.

Russell (2005) presents a series of case studies demonstrating successful energy reduction initiatives in manufacturing. His focus is on the attributes that these organisations have, however he stops short of combining these attributes into an effective methodology. Indeed an observation he makes is that each organisation is unique, and that perhaps there is "no winning formula" for energy reduction.

There is literature emerging on practices that have been successfully implemented in certain manufacturing organisations (Despeisse, Mbaye, Ball, & Levers, 2010). Although the success can be quantified (in kWh savings for example), the literature is unclear on *how* the success was achieved. **Specific interventions are documented in the form of specific actions, but a strategy which allows single actions to be applied to multiple barriers systematically is not.**

2.4. DIRECTION OF THE RESEARCH

The previous section explores the themes in the literature describing what current knowledge is in the field. This provides a good grounding for the rest of the enquiry. It also helps to identify potential areas where knowledge is lacking and thus provide focus for where this enquiry can advance knowledge in this field. The following sections describe the gaps identified and then review the direction of the research.

2.4.1. Gaps in the literature

It is clear from 2.3.1 and 2.3.2 above that there has been some work carried out on uncovering barriers to energy reduction in a manufacturing context. A list of barriers is provided in 2.2.2 which has been tested in a number of situations and by a number of authors. However the breadth of literature in this area is lacking, with the focus appearing to be on energy intensive industries (Thollander & Ottosson, 2007) or large volume, low value manufacturing (Rohdin & Thollander, 2006)(with the exception of one example of a "van manufacturer"); there is no validation in high value, low volume manufacturing such as in the manufacturing organisation which is the subject of this enquiry.

The list of barriers presented at the end of section 2.2 is also based predominantly on economic theory and has been validated in each industrial case usually by a single person responsible for energy management. The broader organisation (multi-functional) and social aspects have not been taken into account.

> *Gap 1: The list of barriers needs to be validated to also take into account the perception of individuals across organisational functions.*

The literature contains some examples of good practice in terms of manufacturing energy efficiency. These are presented as specific actions which manufacturers can employ without taking into account organisational constraints. Although these actions are useful, they are not presented in a way which allows manufacturers to systematically employ them across their operations. That is, there is no methodology associated with the actions which aims to remove all barriers.

> *Gap 2: There is no single approach for overcoming multiple barriers to energy reduction in the literature.*

2.4.2. Learning from Change Management

The management literature on organisational change discusses many methodological interventions for successfully implementing change (Argyris, 1999; Iles & Sutherland, 2001; Kotter, 1996; Lewin, 1946; Schein, 2004) (Kotter also presents his drivers in the form of barriers in an earlier article (Kotter, 1995)). These approaches have been applied to many different situations across many different sectors, from consumer goods to healthcare, from corporate takeovers to the implementation of IT systems. However the approaches to organisational change have not been applied specifically targeting energy reduction initiatives. Perhaps the only such example is Senge (2010) who adapts his 'five disciplines' for organisational learning (Senge, 1993) into an approach for sustainable change. Here he describes how systems thinking approaches can be applied in organisations wishing to act in a more sustainable way, borrowing many concepts from IE (see section 2.2.1). Senge presents these approaches as *tools* – methods than can be applied individually rather than methodologies providing a step-by-step approach.

There are many improvement methodologies familiar to manufacturers the goal of which is to seek to improve manufacturing efficiency. Examples include lean (Bicheno, 2004; Womack & Jones, 1997) (the goal of which is to minimise waste), six sigma (Pyzdek, 2003) (the goal of which is to minimise variation), the theory of constraints (Goldratt & Cox, 1996) (the goal of which is to maximise throughput), and many others. For a manufacturing organisation wishing to implement an energy efficiency improvement, these approaches are a good place to start.

Lean in particular, with its emphasis on reducing waste, would seem like a very appropriate means of applying interventions focused on reducing energy consumption. Indeed, Kissock (2004) and others (Kissock & Eger, 2008; Seryak & Epstein, 2006) have described how a side effect of implementing lean can be a reduction in energy, but there is little evidence from the literature that organisations are using approaches such as lean for targeting energy reduction as the primary focus. Vinodh et al. (2010) attempt to adapt lean for such a purpose but their approach appears little more than a basic rebranding with no significant methodological upgrades and certainly no consideration for the barriers discussed previously.

The literature on lean tends to focus on the successful application of the classic tools (Bicheno, 2004), but there is little useful knowledge that can be gleaned from success stories. Turesky and Connell (2010) take a different approach and provide one of the few cases in literature which describes the failure of a lean initiative. They go on to show how the failings of the first attempt were overcome in a second attempt by identifying the barriers and designing appropriate interventions.

Although there is a lack of examples in the change management literature on how barriers were overcome, this literature offers a rich source of knowledge on the application of interventions to bring about positive organisation change. Given the more generic nature of the barriers described so far, **this body of knowledge could be a useful source of for answering the second research question on overcoming barriers.**

2.4.3. Developing the enquiry

The gaps presented above show that the research questions are valid; there is clear correlation between RQ1 and Gap 1, and between RQ2 and Gap 2. The gaps also provide some direction on how the research questions can be answered.

In order to answer RQ1 data must be collected from within the unit of analysis covering the specific activities that are currently omitted from the literature, i.e. high value manufacturing. It must also take into account the perceptions of actors within the unit of analysis from a variety of backgrounds and operating in a variety of roles across different functions.

In order to answer RQ2 the barriers evident in the unit of analysis must be analysed to identify patterns so that specific interventions can be applied in a more strategic way to achieve a more significant and more lasting impact than by tackling individual barriers alone. The literature on organisational change may provide insight into how this could be achieved. (See 2.4.2.)

The approach adopted in order to answer the research questions is the subject of the following chapter.

3. METHODOLOGY

This chapter describes the philosophical basis for the research including details of the epistemological and ontological standpoint of the researcher. An introduction is also provided into the selection of appropriate research methods and their suitability in relation to the research questions and the epistemology.

Much of the detail in this chapter is taken from two key text books, with some additional reading carried out using the primary texts where appropriate. These books are listed below and will not be referenced again in the body of this chapter except in the case of direct quotations.

Robson (2002), *Real World Research: A resource for social scientists and practitioner-researchers*
Bryman & Bell (2007), *Business Research Methods*

3.1. RESEARCH PHILOSOPHY

3.1.1. What is Research?

Research is **the development of knowledge by carrying out an enquiry using theory and data.** When data is analysed to develop a theory this is called **induction**. Conversely, when a theory is tested by looking for evidence in empirical data this is called **deduction**. (See Figure 2 below.) Both are equally valid routes to uncovering knowledge and are often used consecutively in research. Exactly how the research is carried out, whether predominantly inductively or deductively, is very much dependent upon the philosophical standpoint of the researcher, particularly what the researcher believes to be acceptable knowledge.

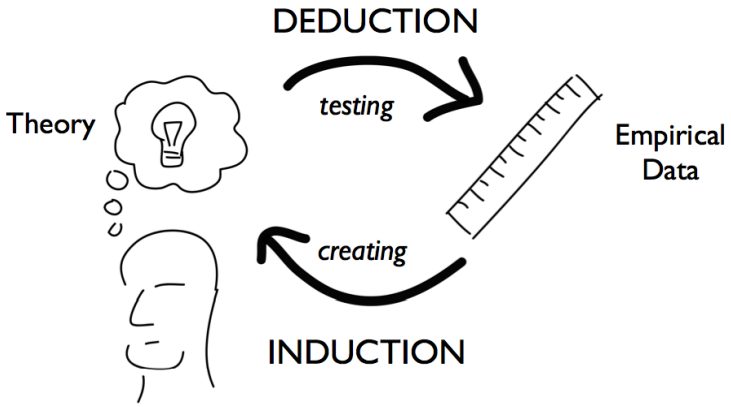

Figure 2 - Deduction and induction in research

3.1.2. What is Knowledge?

The start point for any research activity is to determine what constitutes knowledge in that particular enquiry. This is known as the **epistemology** of the research. Epistemology is more than describing what an acceptable outcome from the research will be; the epistemological standpoint of the research also defines what an acceptable (or unacceptable) route will be to uncover that knowledge.

The two main epistemologies are **positivism** and **interpretivism**; if different epistemological standpoints were represented on a continuum, these would be positioned at either end.

Positivism is the classical, natural sciences view of research where knowledge is perceived as being completely *objective*. Positivists will generally collect *quantitative* data to test a theory (deduction) with *factual* conclusions drawn. Interpretivist (or phenomenological) research is based on more qualitative data. Here knowledge is perceived as being more subjective and often dependent upon the particular situation being investigated. An interpretivist epistemology is therefore appropriate for studying human interactions and perceptions, and thus is widely used in the social sciences.

3.1.3. What is the Nature of the Unit of Analysis?

When looking at social activities and their constructs, such as organisation and culture, the researcher must also consider what the nature of such activities is. This is known as a research **ontology**. As with epistemologies, there are two extreme points of view. (See Figure 3 below.)

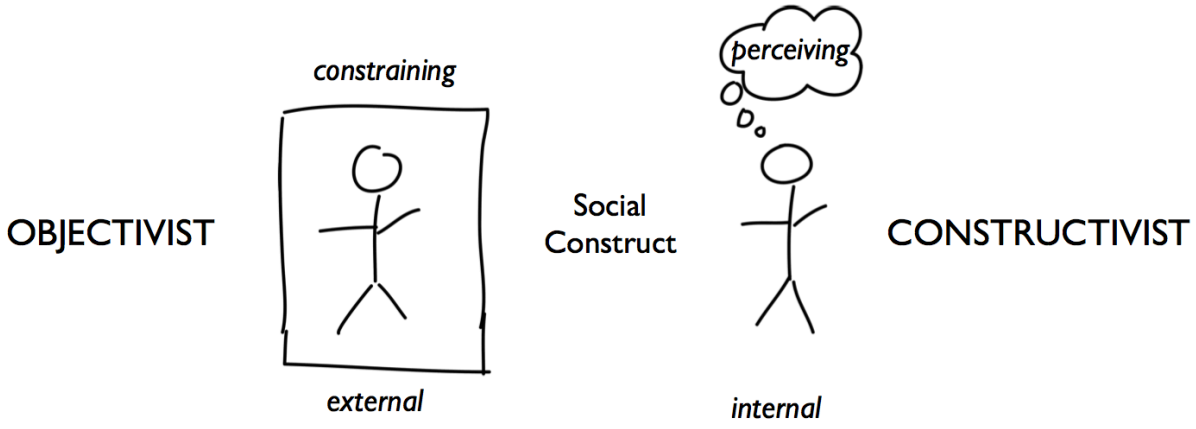

Figure 3 - Ontologies

Objectivism is the view that social constructs exist as external entities which provide constraint to the actors within them. This has a parallel with the positivist epistemology, and social constructs in an objectivist ontology almost take on an objective quality. **Constructionism** on the other hand views such constructs as existing only within the mind of the actors operating in them. Thus for a constructionist ontology the construct of culture for example is constantly changing depending on the perception of people within that culture, and indeed may be different for different people within the culture. Thus for a constructivist knowledge itself is constantly changing and can almost be considered indeterminate.

3.1.4. The Purpose of an Enquiry

An enquiry is carried out to provide access to new knowledge. Traditionally, there are three types of research that may be carried out over the course of an enquiry, each with a different purpose. **Exploratory** research is focused on understanding what is going on in a unit of analysis and typically will provide new insights into a little understood field. This mode of research is inductive, generating hypotheses. **Descriptive** research is the painstaking documentation of reality in the unit of analysis aimed at accurately describing the "as is" situation, perhaps in an area in which exploratory research has been conducted previously. **Explanatory** research involves analysing data to identify patterns and causal relationships in order to explain why a particular situation or phenomenon exists.

In addition to these three traditional modes of enquiry a further mode is also often described. **Emancipatory** research is action-based, the purpose of which is to bring about a change in a unit of analysis.

These four types of research may occur at different stages in the same enquiry.

Burrell & Morgan (1979) provide a way of looking at the purpose of an enquiry from a business research perspective which has parallels with the ideas presented in 3.1.3 above. They present **Four Paradigms** which can be defined as quadrants on set of Cartesian axes. (See Figure 4 below.)

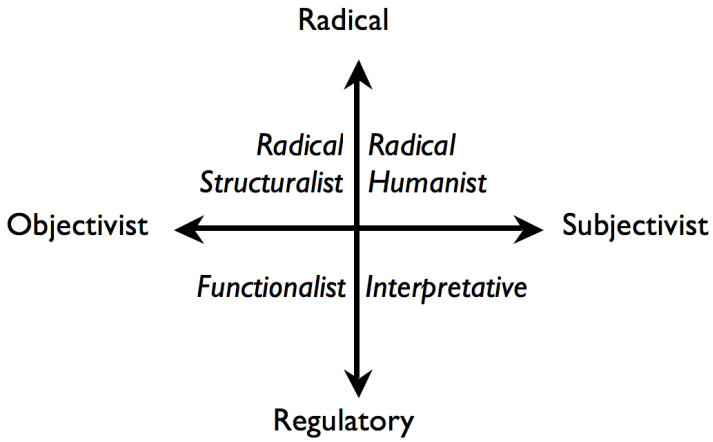

Figure 4 - Four paradigms of an enquiry (based on Burrell & Morgan, 1979)

The ordinate axis is the continuum from *objectivist* to *subjectivist*, which is similar to the continuum presented in the definition of ontology above and thus describes the ontological standpoint of the research. The abscissa on the other hand is a continuum representing the purpose of research - from *regulatory*, which is about describing an "as is" situation, possibly with a view to changing it, to *radical*, which is more focused on describing the "to be". The four paradigms sit between these axes and are: **Functionalist** (regulatory-objectivist), **Radical Structuralist** (radical-objectivist), **Radical Humanist** (radical-subjectivist) and **Interpretative** (regulatory-subjectivist). The questions asked by the researcher will be very different depending on what quadrant the enquiry is most aligned to.

3.1.5. The Researcher and the Research

Although knowledge may be considered objective or subjective as described above, in practice the act of actually carrying out an enquiry will lead to some subjectivity in the results, particularly in business or social research. This is because the **values of the researcher** will have an influence on the outcome of the research. This has epistemological implications when designing the research and selecting appropriate methods. If the researcher wants to be as objective as possible then steps must be taken to completely eradicate any preconceptions (Durkheim, 1938). Conversely, a researcher may chose *conscious partiality* as their epistemology, which is a belief that knowledge can only be achieved by personal identification with the subject matter (Mies & Shiva, 1993). It is more likely that research in the real world will fall somewhere between these two extremes, and that the researcher should deal with subjectivity by being **reflective** and understanding what subjectivity his or her values bring to the research.

The topic of the research and the nature of the unit of analysis can influence the epistemology and subsequent research design. For example, as described above, research in the natural sciences domain will almost always have a positivist epistemology, whereas research into social systems may be more interpretivist.

In order to ensure the values of the researcher have a limited effect on the outcome of the enquiry certain quality checks should be carried out by the researcher. These are described in more detail in 3.4.3.

3.2. THE NATURE OF THIS ENQUIRY

The purpose of this research is to identify the barriers which exist to energy reduction inside a particular manufacturing organisation (RQ1) and to postulate ways of overcoming those barriers (RQ2). This is an *inductive* approach to research as described above, and is appropriate given the more *subjective* nature of the barriers in this case. Barriers here are organisational in nature and relate to the corporate culture and the perception of individuals rather than being objective in nature as technical barriers may be. Thus from an epistemological point of view **this research can be considered more interpretive**. A positivist approach would be unsuitable given the more qualitative data such an enquiry will collect and analyse.

In this research the researcher is also a practitioner, since the researcher is an actor within the unit of analysis with a vested interest in the results. (See 3.2.2 for more on practitioner-researcher strengths and weaknesses.) Given the more subjective nature of the research, and the proximity of the researcher to the topic being researched, great care must be made in developing an appropriate research strategy and using appropriate research methods to avoid bias and ensure the research is of a high quality.

The following sections outline potential research strategies appropriate for working with an interpretivist epistemology focusing in on action-based research. A range of appropriate methods are also introduced.

3.2.1. Research Strategy

Before conducting an enquiry it is important for the researcher to decide on the most appropriate strategy for collecting and analysing the data available in the unit of analysis. A research strategy can either be **fixed** or **flexible** and the choice depends on the purpose of the research and the type of data the researcher expects to collect and analyse.

A fixed research strategy is generally best suited to the collection and analysis of quantitative data. An **experimental** fixed research strategy will involve the altering of variables in a controlled manner and the observation of the consequences of changing each variable. Such a strategy is generally *explanatory* in nature - that is, it seeks to identify patterns and causal relationships. **Non-experimental** research strategies are more *descriptive* in nature, with the purpose of the research being to collect data to provide a picture of the current situation without altering it.

Flexible research strategies are more suited to qualitative data collection and evaluation and are often *exploratory* in nature. Three common traditional flexible strategies used in manufacturing research are the **case study**, **ethnography** and **grounded theory**. Case studies involve the collection of data from a single or multiple specific sources as 'cases' which are then analysed. Ethnography is about gaining an understanding of how a specific group or organisation interacts with its environment. This too can be *exploratory* in nature, with the research generating hypotheses as to why the group acts in the way it does, but it can also be *emancipatory* in nature, with the research focusing more on identifying opportunities for action. A grounded theory approach is again exploratory, based on the principle that hypotheses should be grounded on data collection, which is often structured and codified.

The different research strategies clearly have a close association with the philosophical standpoints discussed previously. Fixed strategies are more appropriate for positivist epistemologies, whereas flexible strategies are more able to deal with the more qualitative and non-deterministic data found in interpretivist epistemologies.

It has already been noted that the qualitative nature of the data associated with the barriers to energy reduction in manufacturing may lead to a more interpretivisit epistemology. **An appropriate strategy for dealing with this data is therefore a flexible one.** This is conducive to more exploratory research using inductive processes.

In addition to the three traditional flexible strategies described above, **action research** is another appropriate flexible research strategy. This is described in more detail in the following section.

3.2.2. Action Research

Action research is a research strategy which seeks to learn about organisations by trying to change them (Lewin, 1946). It is thus a useful exploratory (or emancipatory) research strategy which fits in with the epistemology of this research. It is about both improvement and involvement and by its nature involves the active participation of the researcher in the unit of analysis. It is concerned with theory, not just action, generating emergent action-grounded theory through its systematic and reflective process (Eden & Huxham, 1996).

Action research involves systematically applying interventions to a unit of analysis in order to solve a problem, observing the results of the interventions and designing further interventions in an iterative fashion (Argyris, Putnam, & Smith, 1985). This process is usually shown as a spiral or virtuous circle. The typical steps in an action research-based enquiry are shown in Figure 5 below (from (Robson, 2002) after Bassey, 1998) which also includes some detail about the data collected during this enquiry (see Chapter 4).

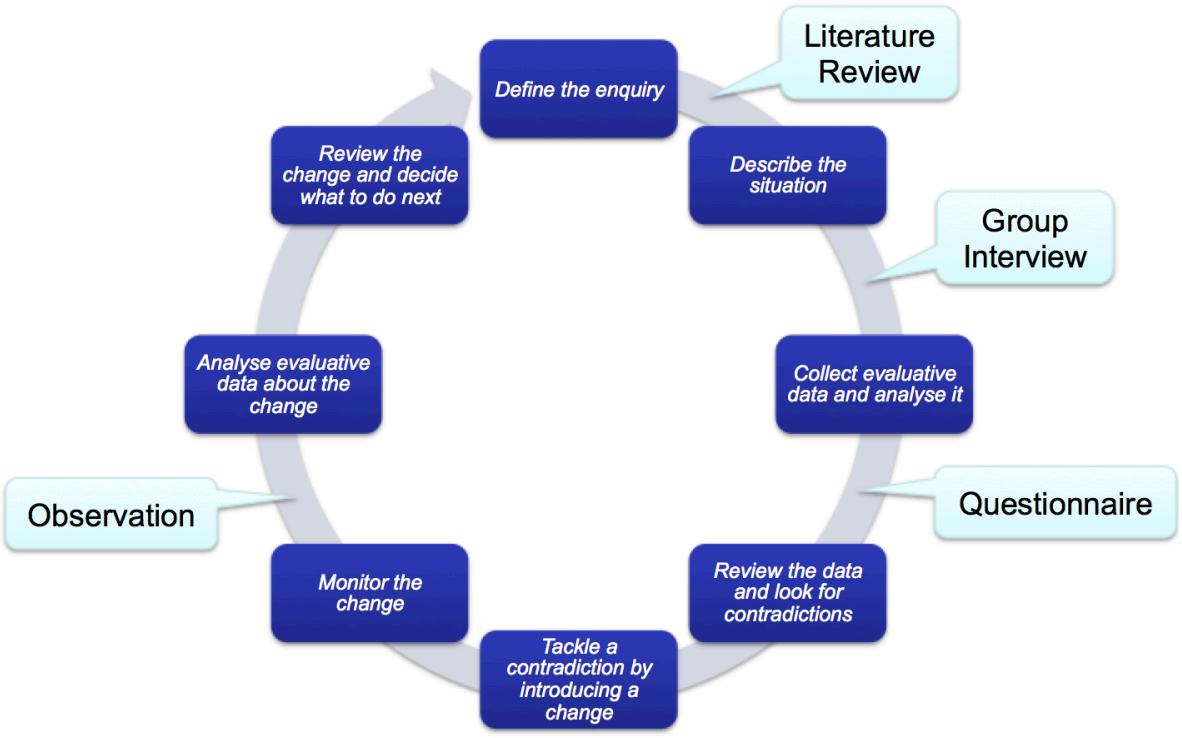

Figure 5 - Action Research Cycle

These steps are repeated in order through each iteration of the action research cycle. Given the scope of this enquiry this cycle will be carried out once only.

The idea of a practitioner-researcher is at the heart of action research, and it is this aspect of the approach which gives it both its power and its weakness. Practitioner-researchers have good access to insider knowledge, that is, knowledge which is not readily accessible through external researchers. Practitioner-researchers also have the skill and ability to apply interventions to their specific unit of analysis, and the vested interest they have in the outcomes means that these interventions will tend to have a positive influence. However, being embedded in an organisation means that the needs of the organisation will often be put before the needs of the research, having an impact on the time spent on research and also introducing bias. The practitioner-researcher is generally a practitioner first and a researcher second. Winter (1989) offers advice for researchers of this type and suggests that any research must be distinct from professional practice and that extra care must be taken in ensuring that the methods used are both accessible and rigorous.

Given its close association with practice, and the fact that the researcher in this enquiry is also a practitioner, action research was selected as the most appropriate research strategy. Action research bridges the two worlds of research and practice enabling researchers to make positive contributions to practice - a key requirement from the manufacturing organisation - and also enables practitioners to carry out improvements in such a way that forms a contribution to knowledge. Compared to the other research strategies discussed, action research is the most appropriate for this enquiry.

The research design will be based on the steps described above and is detailed in 3.3. Appropriate tools for use in an action-based enquiry are detailed in the following section.

3.2.3. Research Methods

The research questions described in the Introduction provide a direction to the enquiry and to some extent determine the type of data that must be collected. When taken in context with the research philosophy and strategy described above, this allows the researcher to select the most appropriate methods - or tools - for collecting that data. The majority of data collected in this research will be qualitative, or intangible data. Some research methods for collecting this type of data are described below.

In order to collect data about what people do *in public* and how they interact with their environment **direct observation** is the most appropriate method. Here the researcher makes notes on what s/he observes in the unit of analysis, and may thus be prone to the subjectivity brought in through the researcher's own values and beliefs. To collect data about others' beliefs, values and opinions (to understand the unit of analysis from the perspective of another actor) **interviews and questionnaires** should be used. Care must be taken when using these methods to avoid a response bias - where an interviewee/respondent may answer a question according to what they believe is an acceptable answer rather than what is truthful. Interviews and questionnaires may thus also be used to determine what people do *in private*, acknowledging the difficulties with obtaining accurate data in certain circumstances.

All these methods can range in the level of structure with which they are applied by the researcher. A journal of direct observation could take the form of a rich narrative, for example, which allows a range of data to be captured but makes analysis difficult; or the journal could be very heavily codified and structured making analysis easier, potentially enhancing quality but often at the expense of missing some data. Interviews too can be unstructured and more like an open discussion, semi-structured with a few guiding questions, or fully structured almost taking the form of a verbal questionnaire. The application of structure will largely depend on the epistemology of the researcher.

Although this research is interpretivist in its epistemology and is focused on what people *perceive* as barriers, the theories induced from this qualitative data can also be substantiated with quantitative data in a more positivist/deductive way. Although from an epistemological point of view this is irrelevant, from a research quality point of view this will to some extent protect the validity of the research from challenges to conclusions drawn from qualitative data alone. Research methods which deal with quantitative data may therefore also be appropriate. This could include **searching company documents** for documented evidence to back up the opinion expressed by an actor. Examples of company documents could include policy statements and directives, meeting minutes, risk registers and issue logs, project plans and other project documentation. These may be able to provide evidence of barriers by providing measurements of the extent of a barrier or by backing up opinion.

These methods are described in more detail in 4.1 and given context relative to this enquiry.

3.3. RESEARCH DESIGN

This section describes the design of the research as a number of distinct phases of data collection, analysis and intervention which broadly follows the action research strategy described in 3.2.2. The tools discussed in 3.2.3 are also presented aligned to this strategy.

The figure below (Figure 6) gives an outline of the practical activities the researcher will carry out and is taken from the top level research plan. The phases of action research (from 3.2.2) are shown which are described in more detail below.

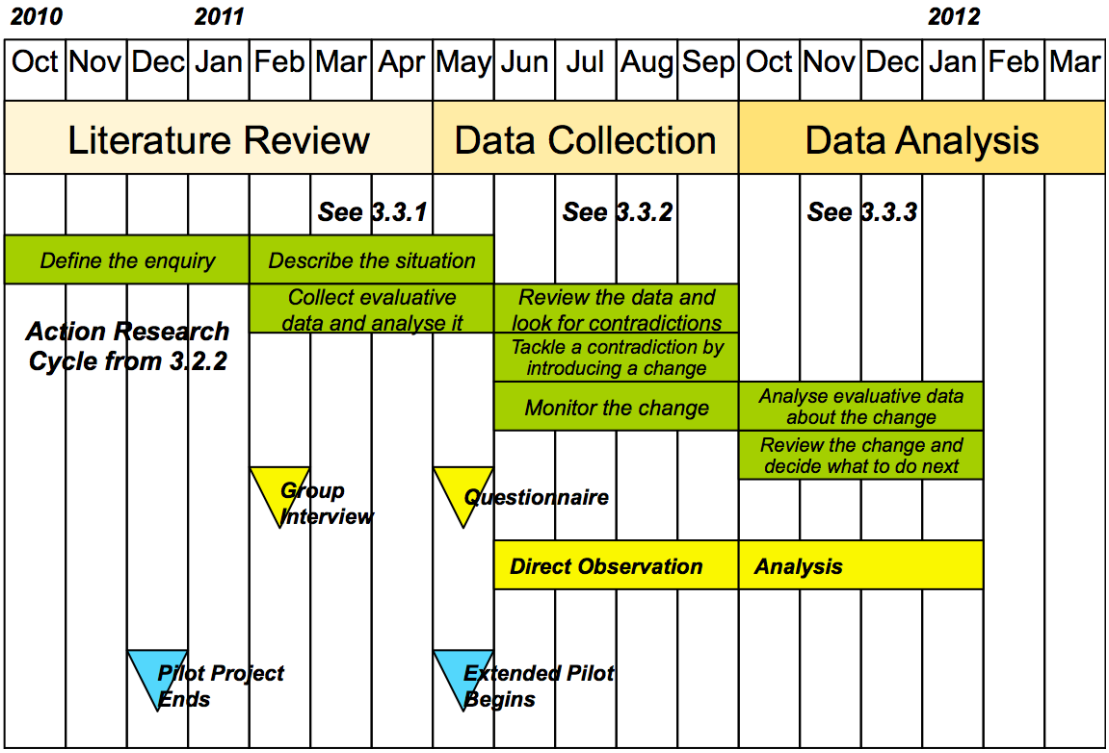

Figure 6 - Research Activities

3.3.1. Describe the situation and collect data

Energy reduction activities have been carried out previously within the unit of analysis. The first phase of research will seek to identify the barriers encountered by means of a semi-structured group interview involving all the relevant actors which will be analysed to identify any barriers. (See 4.2.)

The barriers identified from the interview will be combined with the barriers identified in the literature review and a questionnaire will be developed to assess how other people within the unit of analysis perceive the barriers. The questionnaire will be administered to a range of actors who are likely to be involved in future energy reduction activities. This will provide a good baseline on perceptions of barriers within the unit of analysis and allow suitable interventions to be designed. (See 4.3.)

3.3.2. Introduce and monitor changes

The interventions will be applied within the unit of analysis and their impact determined by observing a number of energy reduction projects within the unit of analysis. Direct observation will be made by the researcher to determine, a) what impact the interventions have had on the barriers they were designed to overcome, b) if any new barriers are apparent. Observation will be supplemented by the collection of quantitative data if possible. (See 4.4.)

Given that the researcher is also a practitioner and actor within the unit of analysis, it is expected that interventions to overcome some barriers will be implemented "on the fly" in order to progress individual projects. It is important that any changes to the methodology or any other interventions implemented by the researcher are fully documented so that contribution to research is not sacrificed.

3.3.3. Review the change and decide what to do next

As more projects are carried out, it is expected that patterns will emerge from the observation of barriers and from observing the effect that many small interventions have on the barriers. This will allow the researcher to better define the list of barriers. It will also allow the researcher to refine any interventions which have already been employed and to develop interventions which have not or cannot be implemented inside the scope of the research, e.g. organisation-level interventions. (See 5.4.)

3.4. CARRYING OUT THE ENQUIRY

3.4.1. Practical Considerations

When developing a research strategy one must also take into account the practicalities of conducting an enquiry given the constraints of the particular unit of analysis. A key constraint will be what **access** the researcher has to various parts of the unit of analysis and thus what data the researcher is able to collect. The amount of time the researcher has to access the data is also a key constraint.

For a practitioner-researcher access is rarely a problem, since the researcher will be embedded in the organisation and will generally have access to a broad range of data on a daily basis with the time constraints being limited by the duration of the enquiry itself rather than access. However it may often be more difficult to collect some kinds of data, with some people more willing to share their opinions with an external researcher than with an internal colleague, who they perceive may have their own agenda within the organisation.

3.4.2. Balancing Contribution to Knowledge and Practice

In this enquiry the researcher is an active participant in the unit of analysis with both research objectives and clearly defined expectations in terms of practice meaning that the practitioner-researcher effectively has two sets of objectives. As long as these are aligned there is no problem; that which contributes to knowledge has a benefit to practice and vice versa. However sometimes these sets of objectives may not be aligned and the practitioner-researcher may find him/herself being pulled in different directions. Whilst the demands of the organisation employing the researcher will always take precedence, it is important that the researcher remains objective and reflective to ensure that the research carried out is of real value, and not just in terms of contribution to practice.

One way of maintaining this focus on contribution to knowledge is to clearly define the research objectives (in the form of research questions) from the outset and to constantly ask the question, "*How does what I am doing now contribute towards the research objectives?*" Another way of ensuring the output contributes to knowledge is to clearly define a research strategy and, as far as is practicable, stick to it. This goes some way to helping to ensure the research is of a high quality.

3.4.3. Quality Checks

An important part in the development of any enquiry is to ensure that it is designed and documented in such a way that someone else conducting the enquiry following the specified methods would get the same results. This element of research quality is termed the **replicability** of the research.

Another quality check is that of research **reliability**. For research to be considered reliable it must build up a consistent (and to some extent a believable) story about the unit of analysis and avoid bias. Unusual methods, sequences or omissions should be avoided.

The outcome of research must also be checked for quality. The path to any conclusions that the researcher draws must be obvious in its explanation, clearly showing *causality* between the *observations* the researcher makes and how the researcher *interprets* those observations. This helps to ensure the **validity** of the research, which is a third and final aspect of research quality.

These checks are discussed again at the end of the thesis (see 6.4) detailing how they were applied throughout and thus how the conclusions drawn are of a high quality.

4. DATA COLLECTION

The purpose of this chapter is to describe how data was collected from the unit of analysis over the course of the enquiry. In section 4.1 the chapter begins with a reasonably detailed overview of the kinds of methods appropriate for the type of enquiry as defined in the previous chapter. It goes on to describe how these methods were applied in sections 4.2-4 with some initial analysis also shown.

4.1. TYPES OF DATA

The purpose of this research is to identify barriers to reducing energy in manufacturing and to identify possible courses of action to overcome these barriers. Thus the data being collected in this research is **evidence of the existence of barriers**.

The research is limited in scope to a single manufacturing plant which in turn affects the type and volume of data available to determine the existence of barriers. This data may be collected by the researcher in different ways. The following provides an overview of the methods used in this research including the types of data that can be accessed through each approach.

4.1.1. Opinions and Experiences of Actors

Opinion-type data are that which are based on the perception of individuals operating within the unit of analysis and may be rather subjective. This type of evidence is appropriate given the interpretivist epistemology of this enquiry, and given the gaps found in the current literature (see Gap 1 in 2.4.1).

It may often be difficult to find documented evidence of barriers (see 2.4.2) since information on issues within an organisation may not be presented in an obvious way. Through accessing the opinion and experience of actors within the unit of analysis it is more likely that barriers and organisational issues will be uncovered.

This kind of data cannot be accessed directly and thus tools and techniques must be applied so that the perception of individuals can be recorded. The opinions of the actors within the unit of analysis with respect to barriers were collected in this enquiry in two main ways: face-to-face **interviews** and paper-based **questionnaires**.

4.1.1.1. Interviews

Interviews are used for accessing the opinions and experiences of actors within the unit of analysis. Interviews involve a verbal interaction between the researcher and one or more people. The interview can have a very definite structure (e.g. completely scripted with a list of questions to be asked), be semi-structured (e.g. areas of interest with open questions) or unstructured. The interviewer-researcher will make notes during the interview or record the interview for transcription. The researcher-interviewer must strike a balance between ensuring that the interviewee answers the questions without leading the interviewee towards an answer. Indeed, the selection of question and the way in which it is asked can influence the response given; the interviewee may respond in what they think is an acceptable way rather than reveal their true perception. This is known as **response bias**.

Group interviews can pose a different set of problems where it is not the researcher-interviewer who can influence the responses but the other people in the group. Here interviewees may be even more likely to respond in what they perceive to be an acceptable way, this time not only what they believe is acceptable to the researcher but also what is acceptable to others in the group. Group dynamics will also play a part in the direction of a group interview. Naturally extroverted interviewees may tend to lead the group and gather support for the point they wish to make whereas introverted interviewees may not be willing to speak up in front of the group. The researcher must therefore also be a good facilitator, able to encourage all members of the group to speak.

In this enquiry a group interview was used to uncover the barriers as perceived by a number of actors involved in a pilot of an energy saving initiative in part of the unit of analysis. (See section 4.2.)

4.1.1.2. Questionnaires

A questionnaire is similar to a structured interview however it does not necessarily involve verbal interaction between the respondent and the researcher. A questionnaire will consist of a number of set questions which the respondent will be asked to answer. Questions range from being quite open, where the respondent can write as much or as little as s/he wishes against a particular question, to being very structured, often with a respondent being asked to rank the extent to which they agree with a particular statement (e.g. a Likert scale).

Questionnaires allow a large volume of data to be more easily processed and codified and allow a researcher to apply statistical methods to the results and to look for statistically significant patterns. For this reason questionnaires are most appropriate for larger sample sizes. Since questionnaires are usually completed remotely from the researcher, response bias may also be less significant, particularly if the respondents are permitted to complete a questionnaire anonymously. The bias introduced unintentionally by the researcher through leading or poorly phrased questions may still be a problem. For this reason it is good practice to pilot any questionnaire before administering widely.

In this enquiry a questionnaire was issued to a group of actors within the unit of analysis who were about to be involved in a number of energy saving projects. The respondents came from a variety of functions with a range of experience. The purpose of the questionnaire was to understand the perception of barriers before any training had taken place in the new methodology to understand the 'as is' state in the unit of analysis. (See section 4.3.)

4.1.3. Direct observation

Some data about the unit of analysis are not accessible by *asking* the actors within the unit of analysis (4.1.1) and may only be accessed by *observing* the actors. Direct observation - and participation - is a key part of the research strategy for this enquiry and is a useful means of accessing a broader set of data. Such data involves the more intangible outcomes from activities and interactions within the unit of analysis, such as the behaviours actors show, unminuted comments in meetings, or statements made to the researcher in confidence.

Observations can be noted down by the researcher in a **journal** and are generally in free, unstructured text, since this way the researcher can capture unlimited details about any observed activity. A researcher may then wish to codify the journal in order to facilitate subsequent analysis. For some enquiries it may be appropriate to create a structure first to facilitate note-taking.

Since the researcher is the instrument through which the observations are made the researcher must take care to avoid bias and imposing his/her own values onto the unit of analysis. This can be done by taking a consciously *reflective* approach to data collection (see 3.2.2), and by ensuring that the views of researcher are triangulated from other sources.

In this enquiry, the researcher used a research journal to note observations in a generally unstructured manner to allow the richness of data in the unit of analysis to be captured. The observations were not explicitly codified but the researcher used key topics to guide observations noted in the research journal. For example, when key barriers were starting to emerge, the researcher collated observations against individual barriers in dedicated sections. Any other relevant supporting data was also referenced in context in the journal - e.g. the appropriate company documents to substantiate an observation such as meeting minutes. This ensured a good degree of triangulation and help to reduce any effect of researcher bias.

4.1.4. Company Records

Company records comprise data that are formally written down which can be treated as objective evidence and may be directly measurable. Examples of company records are: project reports, meeting minutes, technical memos, policy documents, organisational structures, etc. Also of relevance to energy reduction will be meter readings and other data relating to energy consumption. This type of evidence supports a positivist epistemology – that is, barriers can be said to exist if there is empirical data to support their existence.

Given the interpretivist epistemology of this research, company records were not used as a primary source of data but rather as a means of triangulating the perceptions of the actors which were expressed (4.1.1) and observed (4.1.2).

Although often more quantitative and objective in nature, company records are only a *snapshot* of reality inside the company. Policies change, responsibilities move, plans get re-baselined - and so the context of company records is important as this allows the researcher to understand the timeframe in which the data can be considered relevant.

Data such as meter readings, schedules and costs are usually quantitative and may often be recorded in an automated way without any human intervention. However some data are produced manually. This could mean that errors exist in the data, such as in manually read

meters, but could also mean that the data are more subjective in nature, such as opinions expressed in meeting minutes and policy documents. Such documents may be treated as more objective representations of the reality inside the company only when they are approved by a diverse group of people.

Project-related data will generally be produced by the project manager and then approved by relevant stakeholders. This presented a potential problem with bias, since the researcher was also the project leader and thus could heavily influence some of the company records relevant to the enquiry. In an attempt to remove this bias as much as possible the researcher, working with management in the unit of analysis, sought to employ an independent project manager. The management employed such a project manager on a temporary contract and the majority of the later project data was produced by him.

4.1.5. Data Collection Strategy

The tools described above were applied at different stages during the research. An initial grounding in the research area was gained both through a review of the published literature and also through carrying out a **group interview** with people involved in the process of implementing energy improvements within the unit of analysis. This provided an initial list of barriers which in turn was validated through a **questionnaire** administered to additional actors within the unit of analysis, including some with little or no experience of energy reduction. At this point a new phase of improvement activities began in the unit of analysis. During this time the researcher actively participated in the identification and implementation of improvements, **observing** barriers as they occurred and recording them in a research journal.

The following three sections describe in more detail how data was collected in each of these three phases and include some initial analysis.

4.2. BARRIERS FROM THE GROUP INTERVIEW

A number of barriers to manufacturing energy reduction have been identified in the literature, a summary of which can be found in 2.2.3 Table 1. Although this list is useful its validity inside the unit of analysis has not been proven (Gap 1). Indeed there may be barriers which exist inside the unit of analysis which cannot be adequately categorised by this list. Thus in order to expand this list whilst maintaining relevance, additional barriers were sought from people in the unit of analysis with experience of energy reduction in manufacturing.

In 2010 prior to this enquiry, the researcher carried out a project to reduce energy in a manufacturing process in the unit of analysis with minimum capital investment. The project lasted five months and resulted in savings of around 70% within the process perimeter. The project was deemed a success and the approach used developed further in order to be deployed more widely. A detailed account of the approach and the resulting savings is documented by the researcher (Lunt & Levers, 2011).

In order to identify the barriers which occurred during this project a **semi-structured group interview** was conducted with the project team. The team consisted of **four** people excluding the interviewer and the interview lasted approximately **one hour**. The discussions were centred around the two questions: "*What went well during the project*?" and, "*What went badly*?" which gave the interviewees freedom to express their opinions openly and extensively about the project performance. From the interview the following eleven discrete barriers were identified (see Table 3).

Unlike the barriers from the literature review, these barriers are encountered during project *execution* rather than *initiation*. The majority of barriers described in the energy efficiency literature answer the question of why initiatives haven't been tried at all rather than the question of why initiatives have stalled or failed. Examples of unsuccessful execution are absent, unless looking more generally at the change management literature (Turesky & Connell, 2010).

It thus becomes quite difficult to align these to the detailed taxonomy based on Sorrell et al. (2000), since at this point these barriers could be considered to be *effects* of the more fundamental barriers. *Inadequate resourcing*, for example, could be a result of the *culture* of the organisation, or could also be due to perceived *hidden costs* associated with a resource working on another project, which itself could be the manifestation of *split incentives* within an organisation. This apparent causality will be discussed in more detail in subsequent chapters.

Table 3 - Barriers from the post-pilot group interview

Barrier	Evidence from Interview
Inappropriate Equipment	*"The [power] logger we had was ancient… The battery [was so poor] we couldn't even record data for a single shift, let alone a week."*
Inadequate Resourcing	*"The 'day job' comes first." "[Being on different shift patterns] meant that it was difficult to work together." "I wish [my manager] could allocate some time each week for me to work on [energy saving projects]. But if [an issue occurs which could stop production elsewhere] I've got to drop everything and work on that."*
Unclear Objectives	*"We had no deadline, no manager on our backs." "How much [energy] were we supposed to save anyway? There were no targets we had to meet."*
Lack of Structure	*"The on-the-job training wasn't what I was expecting." "We could have done with meeting more regularly." "[The project leader] made some assumptions about our knowledge of the process… [and] our ability to [carry out certain tasks]." "We need better communication with other teams." "[The project] should form part of our personal objectives [which we are appraised against each year]."*
Lack of process knowledge	*"I don't know anything about [the manufacturing process being improved]."*
Complexity of process	*"There's been so many changes to the [process control system] that it's like spaghetti! …We don't know what will happen [to other processes] if we change one [line of code]."*
Reliance on Third Parties	*"We don't understand our own [process control system]. If we want to change anything we always need to get [a specialist external supplier] in – which can end up being expensive."*
Inability to Simulate	*"We can't practise [changing the control system] first. Everything is live. If we [make a mistake] then we could stop the line."*
Fear of Impacting Product Quality	*"We were blamed for [an existing quality issue]. It's almost like the last person to touch [the process] gets blamed for anything that goes wrong."*
Fear of Impacting Health & Safety	*"When [a minor health & safety incident occurred after implementation, unrelated to the project] they were all ready to put the system back to how it was before. They just wanted someone to blame again…a quick fix with no real investigation."*
Lack of Engagement	*"Because I'm [in a supporting function] I didn't feel as involved in the process as the others…[my manger] allocated less time for me to work on [the project]" "I wish I could spend more time on [energy saving projects], but the day job comes first."*

4.3. BARRIERS FROM THE QUESTIONNAIRE

A survey was conducted by means of a **questionnaire** to assess the attitudes of individuals within the unit of analysis towards energy reduction, particularly with respect to their perception of barriers. The questionnaire contained 36 statements constructed by the researcher which each respondent was asked to rank against a Likert scale. These statements are show below in Table 4.

Statements 11-25 are based on the barriers identified by Sorrell et al. (2000) and used by multiple subsequent authors (see Table 1, 2.2.3). These statements are always presented in a negative way. (For example, the barrier "*split incentives*" is captured in the statement, "*If I reduce energy use someone else will get the benefit.*") If the respondent agrees with this statement it would mean that s/he believes that the barrier does exist inside the unit of analysis.

The barriers identified from the group interview described above (Table 3) do not naturally fall into Sorrell's taxonomy, although parallels can be seen – e.g. "*complexity of process*" could be considered a form of "*imperfect information*". To avoid oversimplification, and to retain some of the context appropriate to the unit of analysis, eleven of the statements (statements 26-36) are based on the eleven issues described above. For balance, these are presented in a positive way

compared to Sorrell's barriers. (For example, "*lack of process knowledge*" is presented as, "*I completely understand the processes in my area.*") In this case if the respondent agrees with the statement s/he believes that the barrier does **not** exist.

The remaining ten statements (1-10) are based not on *barriers* to energy reduction but on *drivers*. Thollander and Ottosson (2007) use Sorrell's barriers in their work and they also identify a number of factors which they consider "driving forces" towards energy efficiency (see Table 2, 2.3.2). As with the issues from the group interview, the driving forces are presented in a positive way. If the respondent does not agree with these statements then it means s/he believes that the driving force does not exist. To infer that this means that a barrier exists instead would be inaccurate, and further conclusions on barriers cannot be made without further investigation.

In addition to the 36 statements, the respondents were asked to describe in their own words what they considered to be the main drivers for reducing energy and the main obstacles to doing so.

A graphic representing the questionnaire showing the Likert scale is given below in Figure 7. A readable version of this is also given in Appendix A, and the specific questions 1-36 are shown in Table 4 below with the corresponding barrier or driver (from Tables 1-3).

Attitudes to Energy Saving Questionnaire ***Date*** _____

Name _____ ***Function*** _____

Please indicate to what extent you agree or disagree with the following statements by circling the appropriate number to the right of each statement.

		Always Disagree	Mostly Disagree	Usually Disagree	Usually Agree	Mostly Agree	Always Agree
1)	"Reducing energy reduces the cost of production"	1	2	3	4	5	6
2)	"Rising energy prices are a real concern"	1	2	3	4	5	6
3)	"Saving energy makes us more competitive"	1	2	3	4	5	6
4)	"Suppliers can help us to be more energy efficient"	1	2	3	4	5	6
5)	"It is important for the company I work in to be 'green'"	1	2	3	4	5	6
6)	"Saving energy is important to me"	1	2	3	4	5	6
7)	"Saving energy is good for my personal development"	1	2	3	4	5	6
8)	"A good company should have a long term energy strategy"	1	2	3	4	5	6
9)	"An environmental management system helps save energy"	1	2	3	4	5	6
10)	"Saving energy improves working conditions"	1	2	3	4	5	6
11)	"Airbus requires unique solutions for reducing energy"	1	2	3	4	5	6
12)	"It is not possible to fully predict the total cost of implementing energy saving projects"	1	2	3	4	5	6
13)	"There aren't enough funds for energy saving projects"	1	2	3	4	5	6
14)	"There are too many risks involved in implementing energy saving projects"	1	2	3	4	5	6
15)	"If I reduce energy use someone else will get the benefit"	1	2	3	4	5	6
16)	"It is the responsibility of another function to reduce energy in my area"	1	2	3	4	5	6
17)	"I don't know enough about energy saving to be able to reduce energy in my area"	1	2	3	4	5	6
18)	"Other factors (e.g. cost) are more important than energy efficiency when making investments"	1	2	3	4	5	6

		Always Disagree	Mostly Disagree	Usually Disagree	Usually Agree	Mostly Agree	Always Agree
19)	"As far as I know, we're already as energy efficient as we can be"	1	2	3	4	5	6
20)	"The information on energy reduction is unclear"	1	2	3	4	5	6
21)	"The people who promote energy saving [redacted] are not completely credible"	1	2	3	4	5	6
22)	"Saving energy isn't important to me"	1	2	3	4	5	6
23)	"Saving energy isn't important [redacted]"	1	2	3	4	5	6
24)	"I can't affect how much energy we use in manufacturing"	1	2	3	4	5	6
25)	"It would be too difficult to change our processes to be more energy efficient"	1	2	3	4	5	6
26)	"I have access to all the equipment I think is required for saving energy in my area"	1	2	3	4	5	6
27)	"I have been allocated sufficient time to work on energy saving projects"	1	2	3	4	5	6
28)	"In terms of energy projects, I understand what needs to be done, how it will be done and by when"	1	2	3	4	5	6
29)	"There is a dedicated team I can turn to for guidance on energy reduction"	1	2	3	4	5	6
30)	"I completely understand the processes in my area"	1	2	3	4	5	6
31)	"I completely understand how the different processes in my area interact"	1	2	3	4	5	6
32)	"I have instant access to all the help I need for saving energy in my area"	1	2	3	4	5	6
33)	"I can accurately predict the impact any improvement will have in my area"	1	2	3	4	5	6
34)	"It is possible to mitigate any risks to quality before implementing an energy saving project"	1	2	3	4	5	6
35)	"It is possible to mitigate any risks to health & saftey before implementing an energy saving project"	1	2	3	4	5	6
36)	"I feel involved with energy saving activities"	1	2	3	4	5	6

What do you believe is the most important reason to save energy [redacted]?

What do you believe is the most significant obstacle to implementing energy saving projects [redacted]?

Figure 7 - Questionnaire Layout

Table 4 - How barriers are described by statements in the questionnaire

No.	Statement in Questionnaire	Barrier
1	"*Reducing energy reduces the cost of production*"	Cost reduction
2	"*Rising energy prices are a real concern*"	Rising energy prices
3	"*Saving energy makes us more competitive*"	Competition
4	"*Suppliers can help us to be more energy efficient*"	Use of ESCOs
5	"*It is important for the company I work in to be 'green'*"	Green image
6	"*Saving energy is important to me*"	Personal commitment
7	"*Saving energy is good for my personal development*"	Ambitious people
8	"*A good company should have a long term energy strategy*"	Long term energy strategy
9	"*An environmental management system helps save energy*"	Env.l Management System
10	"*Saving energy improves working conditions*"	Improved Working Conditions
11	"*Airbus requires unique solutions for reducing energy*"	Heterogeneity
12	"*It is not possible to fully predict the total cost of implementing energy saving projects*"	Hidden Costs
13	"*There aren't enough funds for energy saving projects*"	Lack of access to capital
14	"*There are too many risks involved in implementing energy saving projects*"	Risk
15	"*If I reduce energy use someone else will get the benefit*"	Split incentives
16	"*It is the responsibility of another function to reduce energy in my area*"	Principal-agent
17	"*I don't know enough about energy saving to be able to reduce energy in my area*"	Imperfect information
18	"*Other factors (e.g. cost) are more important than energy efficiency when making investments*"	Adverse Selection
19	"*As far as I know, we're already as energy efficient as we can be*"	Bounded rationality
20	"*The information on energy reduction is unclear*"	Form of information
21	"*The people who promote energy saving in [the manufacturing organisation] are not completely credible*"	Source of information
22	"*Saving energy isn't important to me*"	Values
23	"*Saving energy isn't important to [the manufacturing organisation]*"	Culture
24	"*I can't affect how much energy we use in manufacturing*"	Lack of power
25	"*It would be too difficult to change our processes to be more energy efficient*"	Inertia
26	"*I have access to all the equipment I think is required for saving energy in my area*"	Inappropriate Equipment
27	"*I have been allocated sufficient time to work on energy saving projects*"	Inadequate Resourcing
28	"*In terms of energy projects, I understand what needs to be done, how it will be done and by when*"	Unclear Objectives
29	"*There is a dedicated team I can turn to for guidance on energy reduction*"	Lack of Structure
30	"*I completely understand the processes in my area*"	Lack of process knowledge
31	"*I completely understand how the different processes in my area interact*"	Complexity of process
32	"*I have instant access to all the help I need for saving energy in my area*"	Reliance on Third Parties
33	"*I can accurately predict the impact any improvement will have in my area*"	Inability to Simulate
34	"*It is possible to mitigate any risks to quality before implementing an energy saving project*"	Fear of Impacting Product Quality
35	"*It is possible to mitigate any risks to health & safety before implementing an energy saving project*"	Fear of Impacting Health & Safety
36	"*I feel involved with energy saving activities*"	Lack of Engagement

The survey was administered at the start of a training session on energy reduction, which was attended by the group of **nine people** likely to be involved in the next phase of deployment of the energy saving methodology. The attendees were thus from multiple functions, each with a different level of exposure to energy saving specifically and industrial improvement in general. Each respondent was given time to complete the questionnaire before the training course began which ensured a high response rate (100%). The responses were treated anonymously.

From the questionnaire it was found that **four** barriers were highly likely to exist and **five** others were also likely to exist but to a lesser extent out of a total of **thirty six** (see Table 4). These barriers are presented below.

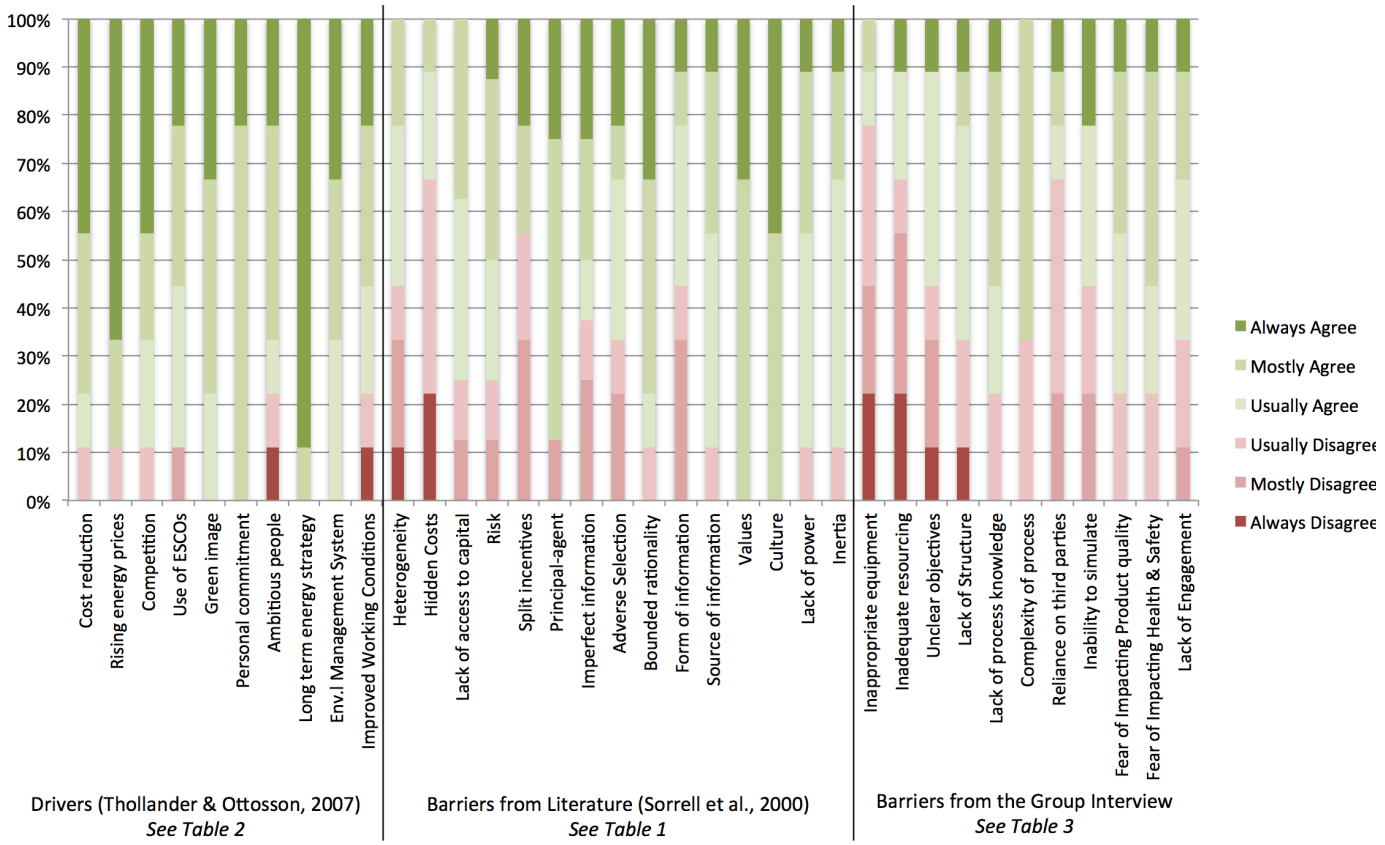

Figure 8 - Questionnaire Results - extent to which the respondents believe the barriers exist

Highly Likely to Exist (>60% of the respondents perceive these as barriers)

- Hidden Costs
- Inappropriate Equipment
- Inadequate Resourcing
- Reliance on Third Parties

Likely to Exist (>40% of the respondents perceive these as barriers)

- Heterogeneity
- Split Incentives
- Form of Information
- Unclear Objectives
- Inability to Simulate

The respondents were also asked to identify their own barriers in free text at the bottom of the questionnaire. Although no new barriers were uncovered (e.g. the most commonly cited barrier was simply "cost", which corresponds to a number of the economic barriers) a number of respondents mentioned "mindset" as a barrier. From the wording of those responses it was clear that although no respondents responded positively to the Values or Culture statements, these could indeed be barriers. The same is true for Inertia, which was also not seen as a barrier.

Thus by excluding those three barriers, the following barriers were deemed **not likely to exist** (<10% of the respondents perceive these as barriers).

- Bounded Rationality
- Source of Information
- Lack of Power

Figure 8 shows how much each respondent believed that each barrier exists. (Note that the graph has been altered such that 'agree' means that the item on the x-axis does not exist as a barrier, and 'disagree' means that it does. This is so that all items can be compared more easily.) Each answer is given equal weighting with no scaling for stronger opinions expressed.

The sample size for the questionnaire was only 9 from a population of over 500 within the unit of analysis (<1%), which means that it is difficult to draw meaningful conclusions from the data presented above. This is because the focus was on people who were going to be directly involved in energy saving projects, not the population at large. These 9 were the most likely people to be involved in the projects, as nominated by their functional manager. Whereas in statistical terms the sample size is rather small, it does provide an insight into the opinions of those actors within the unit of analysis whose actions will have a direct impact on energy activities and can also provide a basis from which a more rigorous investigation into the existence of barriers can be carried out. Due to the targeted nature of the questionnaire and short timescales it was also not possible to pilot the questionnaire prior to being administered.

4.4. BARRIERS FROM OBSERVATION

4.4.1. Application of Interventions

The purpose of the enquiry so far has been to establish what the current situation is within the unit of analysis (the "as is"). This corresponds to the first part of the action research cycle (see 3.2.2) and to the first phase of the research design (see 3.3.1).

At this point in the enquiry some key barriers have been identified based on the perception of individuals. These individuals are about to undertake some improvement work within the unit of analysis, thus it is possible to enter the next phase of action research cycle - to design a number of interventions and observe the effects of these interventions on the new projects (see 3.3.2).

The four key barriers from above are presented in Table 5 below along with the intervention applied.

Table 5 - Barriers and interventions

Barrier	Intervention
Hidden Costs	*The usual approach to business improvement projects used by the manufacturing organisation was adopted as the standard for energy reduction projects. Part of this includes producing a business case for early project sign off, which it was thought would reduce the perception of hidden costs, since the cost benefits would be made more clear earlier on in a project.* *Additionally an FMEA (Failure Mode Effect Analysis) method used inside the unit of analysis for projects involving chemical treatment (i.e. potentially high risk projects) was adopted as a standard quality gate for energy reduction projects. FMEA identifies any potential risks of carrying out a change such as an improvement, quantifying the effect and proposing mitigation. This too was thought to reduce the perception of hidden costs, since potential additional costs could be identified.*
Inappropriate Equipment	*Additional electricity monitoring equipment was purchased and put at the disposal of the project team. This replaced the out-of-date equipment used in the pilot (noted in 4.3).*
Inadequate Resourcing	*A dedicated project manager was hired for leading energy reduction projects. He was based in the Facilities function.* *The senior manager responsible for the unit of analysis (based in the Manufacturing Operations function) was approached for formal buy in of the energy projects being carried out in his area. This was given, which provided an escalation route if resources were not available. However no specific energy-related objectives were set for his team.*
Reliance on Third Parties	*It was not possible to apply an intervention against this barrier.* *The competencies required for carrying out some of the work are not available in house (e.g. controls engineering), nor would it ever be possible to hire someone with such a skillset when the competencies are not considered 'core' to the business.*

4.4.2. Recording Observations in a Research Journal

As the projects were carried out the researcher looked for evidence of these four barriers in particular and also for evidence of other barriers, both those previously identified and any new barriers emerging. Observations were noted in a research journal, referencing who was involved (function and level), on what date, what project was impacted and any other data which could be used for cross-referencing the incident with company documents at a later date. An example of a journal entry is given below:

> *"15th July 2011: Maintenance electricians working on shutdown preparation which means no resource for installing meters. Project #004 stalled as a result."*

The entry shows that the meters are available to be used but no-one is available to install them. This means that the barrier of *inappropriate equipment* has potentially been overcome but that the barrier of *inadequate resourcing* has yet to be overcome. What the entry also shows is that there is a potential barrier relating to *prioritisation*, since the energy project was deemed not as important as shutdown preparation in this case. Finally the entry also references a specific project. By looking through the project documentation it may therefore be possible to quantify the extent of the delay.

Another example is also given:

> *"22nd August 2011: Compressed air usage of machine 26 cannot be determined due to a lack of data on the process (holding up Project #058). No compressed air metering currently exists at a process level. [External company] approached for a quotation on installing a temporary flow meter week 36."*

It was noted in 3.2.4 that the researcher has a vested interest in the success of the projects and thus it is likely that interventions may be implemented on the fly to overcome barriers. This example shows that rather than cancel or postpone a project the researcher was quick to implement an intervention to overcome the barriers of a lack of data and inappropriate equipment. It also shows that in this case the use of third parties was seen as an enabler rather than a barrier.

These observations are as a result of the researcher actively participating in the practical aspects of the improvement projects and to a greater or lesser extent experiencing the barriers along with the other actors. However some barriers were not directly experienced by the researcher but by other actors in the unit of analysis. To observe these barriers the researcher carried out what could be described as **informal interviews** where the researcher discussed barriers with the other actors. These conversations were either initiated by the researcher to elicit a response regarding particular aspects of project execution or were initiated by the actors who volunteered information to the researcher, often with the expectation that the researcher would provide an intervention to overcome the specific barrier.

As well as the observations made of the barriers experienced by actors trying to implement improvements (i.e. the barriers at an *operational* level), observations were also recorded at a more *strategic* level between senior stakeholders and between functions. The following is an extract from notes made during a meeting of senior stakeholders on 15th December 2011.

Finance Director:	*"The function that invests in energy saving projects needs to receive some benefit from the energy reduction."*
Energy Manager:	*"Energy price rises are currently being absorbed by Facilities so that [Manufacturing] Operations get charged a flat rate; Facilities absorb this risk, so Facilities should get a reward for absorbing the risk. You [Manufacturing Operations] want to have no risk and receive a benefit - you want to have your cake and eat it!"*
Operations Manager:	*"Operations doesn't want to make money on saving energy - we're here to deliver product. What we do want is to receive something back for effort spent, otherwise why would we expend the effort in future? There are plenty of other projects to use resource on which do deliver benefit [directly to Operations].* *One of my engineers worked on a project to collect and segregate titanium bolt tails to get the company greater value for scrap. When approached Facilities wouldn't buy the bins, so we did. Facilities get all the additional return and refused to contribute to the project saying savings would go to offset overspend elsewhere. Do you think the engineer felt motivated to work on projects like that again?"*
Energy Manager:	*"Do people think the same thing about health and safety projects? Operations should want to save energy for the good of the company and the good of the environment."*
Improvement Manager:	*"But how can an Operations Manager decide what project to do? There needs to be a common measure across all projects, and that measure is cost. With so many projects competing for resources only a project which provides direct benefit back to the Operations Manager, and helps him meet his objectives, will get done. Cost is a top priority."*

The main argument here is a financial one, namely who should receive the cost benefit from reduced energy consumption. The current financial structure means Manufacturing Operations receive a fixed chargeback for energy - which is beneficial when energy prices rise but does not provide Operations with an incentive to reduce its consumption. This type of problem was uncovered in the literature and is an example of *split incentives*. The lack of financial payback in turn means that Operations may not wish to invest in energy reduction and thus may tend to prioritise activities which do, leading to *inadequate resourcing*.

This example shows that barriers which may not have been perceived by the actors at an *operational* transactional level (i.e. barriers recorded through the questionnaire) may still be apparent at a *strategic* organisation level. It shows that actors actively involved in energy reduction projects may not have visibility of an organisational dysfunction (e.g. principal-agent problems between Operations and Facilities, which <20% of respondents perceived as a barrier). It also shows that this dysfunction could be the cause of operational issues (e.g. inadequate resources, which >60% perceived as a barrier). The concept that barriers which are experienced at an operational level may actually have their roots in the strategic barriers is explored further in the following chapter.

The research journal contains many other examples of observations. The data contained in the research journal, along with supporting information, can give a rich picture of reality in the unit of analysis. This is illustrated in 5.1 by presenting a number of case studies based on observations, which allow the researcher to propose some further interventions.

4.5. SUMMARY

The data collection phase of this enquiry has resulted in a variety of data from multiple sources within the unit of analysis. To summarise, the following data have been collected:

- A **list of barriers** from within the unit of analysis to complement the barriers from literature was collected via a semi-structured **group interview** lasting one hour involving four people.
- The relative **importance of the barriers** was determined through a **questionnaire** administered to nine actors involved in energy reduction within the unit of analysis.
- The barriers were **validated** and the **interaction of the barriers** recorded through **direct observation** which also included informal interviews.

This data starts to address RQ1 by drawing up and validating a list of barriers.

This data will be analysed in the following chapter to better understand the interaction between the barriers and so propose strategic interventions to answer RQ2.

5. DATA ANALYSIS

The previous chapter provides an insight into what barriers exist within the unit of analysis and so helps to answer RQ1. This chapter will build on this by analysing a number of projects carried out within the unit of analysis and so refine the list of barriers, better answering RQ1. The analysis will also show patterns between the barriers which will help to identify ways of overcoming the barriers, thus answering RQ2.

5.1. FROM RAW DATA TO CASE STUDIES

The first phase of research was to understand the current situation within the unit of analysis, which was fulfilled through applying a number of research methods including interview and questionnaire. The second phase of research was to progress from this baseline and understand the impact various actions have within the unit of analysis, this time predominantly through direct observation. When taken in isolation, these observations can provide examples of specific barriers perceived by certain individuals at a certain level and working for a certain function. When taken in the context of a project, multiple perceptions can be taken into account giving a more accurate view of the barriers. The following examples illustrate how barriers were encountered in the context of specific improvement projects. Each barrier is presented in italics followed by a letter (i.e. *barrier [a]*) which will aid reference in subsequent sections. A summary of these barriers is given preceding the case studies in Table 6 below.

Table 6 - Barriers from the case studies

Barriers			
[a] Hidden Costs	[f] Imperfect information; Incomplete information	[k] Inadequate Resourcing; Resource used elsewhere; No dedicated resource	[p] No sense of urgency (Kotter 1996)
[b] Lack of access to capital	[g] Adverse Selection; Non-optimal improvement	[l] Lack of process (& energy) knowledge; Lack of understanding	[q] Limited training (Turesky 2010)
[c] Risk aversion	[h] Bounded rationality; Lack of understanding	[m] Complexity of process	[r] Lack of accountability (Turesky 2010)
[d] Split incentives	[i] Form of information	[n] Fear of Impacting Product Quality	[s] Not a priority
[e] Principal-agent problems	[j] Inappropriate Equipment; Lack of access to appropriate equipment	[o] Fear of Impacting Health & Safety	[t] Unclear who owns what

5.1.2. Operation of a drying tank (Project #001)

The surface treatments process was found to be one of the largest consumers of energy within the unit of analysis. The process consists of a number of enclosed treatments tanks through which parts pass in sequence. The final stage of the process is to dry the parts in such an enclosed tank by forcing air over a heat exchanger and circulating it through the tank. (See Figure 9 below.) Investigations into the process found that the drying tank was one of the largest consumers of energy and that the main fan associated with the heat exchanger was always on, maintaining the tank at drying temperature even outside of production time. An improvement project was therefore launched to modify the controller such that the main fan was only on when required (according to the methodology outlined in Lunt & Levers, 2011).

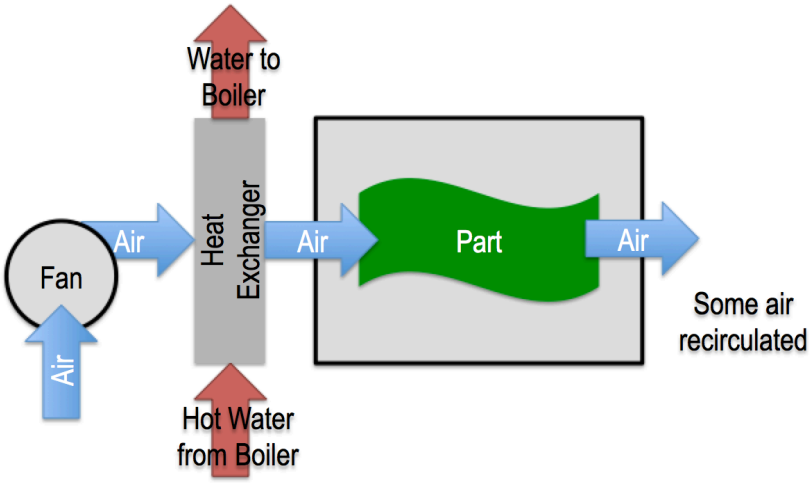

Figure 9 - Drying process

An important stage of the improvement approach is data collection. This was found to be quite difficult, with *incomplete information [f]* on the process – partly due to the *complexity [m]* of the process, and partly due to a *lack of access to equipment for collecting data [j]* (i.e. data loggers). This was exacerbated by having *no dedicated resource [k]* for collecting data – or for carrying out any subsequent improvements. Although the corporate *culture* and the *values* of individuals supported energy reduction activities, energy reduction was clearly *not a priority [s]*, with other operational issues and other improvements always taking precedence over energy projects; there was *no sense of urgency [p]* for carrying out energy projects.

This discrepancy between corporate and personal commitment to energy reduction and the status of energy projects in the unit of analysis raised the question of who was *accountable [r]* for energy saving in a manufacturing perimeter. It was found that the Facilities function is usually responsible for energy reduction activities in this facility; it is Facilities who pay for energy and realise any benefits in reduction, however it is not empowered to act within a manufacturing perimeter. The Manufacturing Operations function is responsible for manufacturing process improvements but energy is outside its scope. So fundamentally there was *no clear owner [t]* for manufacturing energy reduction projects. Indeed, the relationship between Facilities and Operations could be considered a landlord-tenant relationship – which leads to the classic economic barriers of *principal-agent problems [e]* and *split incentives [d]* discussed previously.

When it came to carrying out the project, these barriers persisted and continued to cause delays to the project, particularly in terms of *resourcing [k]*, increasing the elapsed time of the

project. In addition, those responsible for approving the improvements were concerned about the potential *impacts to product quality [n]* and to *health and safety [o]* and also that the project may incur *unintended expenses [a]* through disruption to production. These are valid concerns, particularly in the traditionally risk averse environment of aerospace manufacturing. However these fears could have been allayed but for a *lack of understanding [l]* of the combination of energy and manufacturing factors – which itself could be due to the *limited information collected [f]*, or due to a *lack of training [q]*. This in turn added *additional time and cost [a]* to the project while more data was collected and various mitigations put in place. It also caused the project team to select a *non-optimal improvement [g]* such that less energy was saved than could have been due to the inclusion of mitigations. In this case rather than only heating the enclosure when the product was present, a lengthy warm-up time was included to ensure the enclosure was always at temperature.

5.1.3. Operation of a spray cleaning tank (Projects #034 and #037)

Another large consumer of energy in the surface treatments process is the spray cleaning tank. Here parts enter an enclosure and are sprayed with high pressure warm water to remove surface contamination from a previous manufacturing process (machining). (See Figure 10 below.) Two projects were identified on this process.

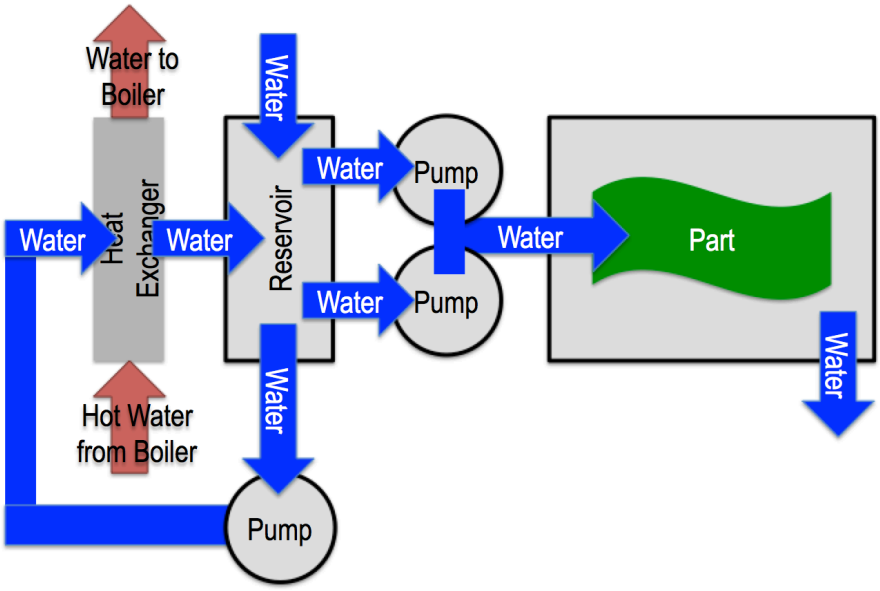

Figure 10 - Spray cleaning process

The first project focused on the spray pumps. The spray nozzles were fed by two high power pumps and it was found that the pressure required for all the nozzles could be provided by one pump alone. Thus the Maintenance function (part of Manufacturing Operations) decided to switch the operation of the pumps to duty and standby rather than both on continuously.

The Maintenance team has a good *understanding [l]* of the process and so a lot of the issues to do with *information [i]* and *risk aversion [c]* were avoided in this case. Maintenance was also able to provide *ownership [t]* for this project, since although it was still unclear who would benefit from the energy savings, Maintenance would clearly benefit from a reduction in maintenance work – and so Maintenance was happy to *fund [b]* and *resource [k]* this project.

However due to the responsibilities of the Maintenance staff this project was still *not a priority [s]* and the "day job" of attending breakdowns etc. always came first, meaning that the elapsed time for the project was long. Additionally *data collection [f]* was still quite difficult, although Maintenance could see the benefits of activities such as this and invested in new measuring equipment for future projects.

The second project focused on the circulation of water through a heat exchanger. The process requires the water to be at a certain temperature above ambient and so water is circulated by a pump through a hot water heat exchanger and into a reservoir from which it is pumped to the spray nozzles. As with the drying process, the circulation pump ensures that the water is always at the required temperature, regardless of whether it is required by the process or not. Due to the higher thermal mass of water, and the resulting longer warm-up (and also cool-down) time, the second project was this time to reduce the operation of the circulation pump to come on intermittently rather than continuously and so maintain the required temperature.

As with the drying process, this project too suffered from a *lack of ownership [t]*. It was still not clear who would benefit from the reduced energy consumption and thus there was a *lack of access to capital [b]* for improving the process and a *lack of resource [k]* to carry out improvements. There were also *objections on health and safety grounds [o]* to altering the operation of the pump as it was believed it played a role in controlling bacterial growth. Initially this was believed to be due to a *lack of understanding [l]* of the biology involved or a *lack of understanding [l]* of the project proposal – thus the *form of information [i]* was changed to better communicate between functions, since each function was used to its own method of communicating improvement projects.

A lack of understanding can simply be due to a l*ack of knowledge [l]* on the subject matter, for example an unfamiliarity with the process or with energy saving practices. The lack of understanding here and in the example in 5.1.1 above could also be described in terms of *bounded rationality [h]*. Bounded rationality is the concept that an individual's decision-making capability is based on the information presented to them (including *a priori* information and prejudices), the time they have to process that information and the cognitive capability of their minds. The limitations on each of these three fronts means that often *non-optimal decisions [g]* may be taken.

5.1.5. Ancillary Equipment in Machining (Project #066)

The previous two examples focus on improvement to the surface treatments process, which was the initial focus of most of the work due to the level of consumption. Also within scope of the improvements is the machining process, where material is removed from metallic prismatic billets with rotating cutting tools to produce individual components. (See Figure 11 below.)

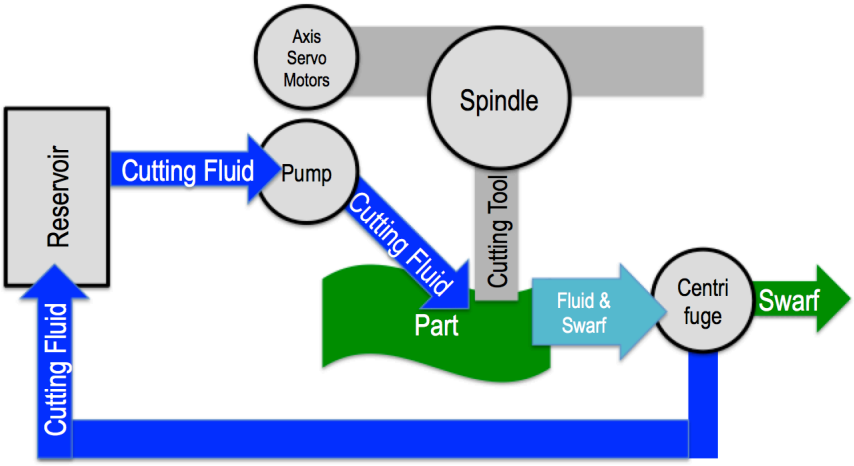

Figure 11 - Machining process

A good profile of energy used in this process is provided by Dahmus and Gutowski (2004) and is shown in Figure 12 below. The x-axis corresponds to the rate of production from 0 to 100% capacity.

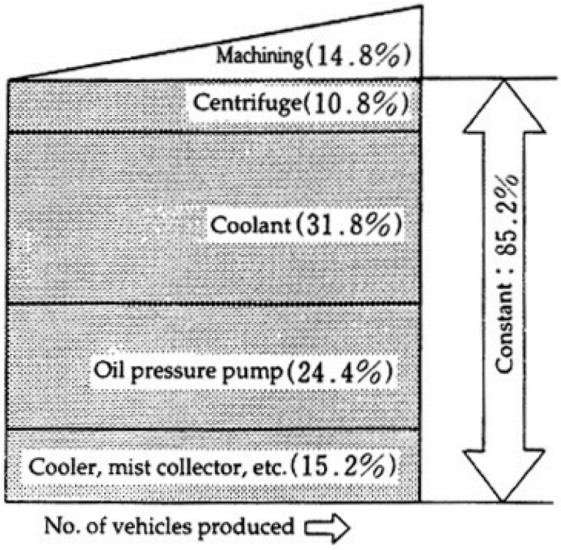

Figure 12 - Energy consumed during machining (from Dahmus & Gutowski, 2004)

As can be seen from the diagram, a large portion (30-85% according to Dahmus & Gutowski) of the energy used by the process comes from ancillary processes such as the coolant system and the hydraulic pumps rather than the cutting spindle. What can also be seen is these are typically independent of production rates since the ancillary equipment is left running outside of production time. This project focused on the use of the emergency stop (e-stop) functionality of the machine to cut power to the ancillary equipment rather than leaving the machine in an energised standby state between batches.

Initially there was much resistance to using the e-stop in this manner. In part this was due to *health and safety concerns [o]* but it was also due to anecdotal evidence that the machine was always difficult to start up again after a power cut, *impacting production [n]* and causing *unintended expenditure [a]*. This shows both *risk aversion [c]* but also a *lack of understanding [l]* of the process. (The purpose of an e-stop is to safely stop the machine in the event of an emergency in a controlled manner, whereas a power cut is completely uncontrolled.) This was exacerbated by the fact that there was no record of testing the e-stop (*lack of information [f]*), which is something which should be regularly tested. The *complexity of the process [m]* also meant that no one really knew which pieces of equipment would be impacted by operating the e-stop (l*ack of process knowledge [l]*).

The conflict between the project team and Operations here is based on the operational requirement that the machine be available as much as possible. Anything which could impact this availability was considered a threat – another example of energy saving *not being a priority [s]*. This also shows a *lack of accountability [r]* for the energy aspects of the process; the main concern of those operating the equipment is availability.

5.3. DEVELOPING A LIST OF BARRIERS

The list of barriers has been built up through this enquiry in a systematic manner. In the Literature Review a list of barriers is presented based on previous work (see Table 1). This is added to in the next phase of the enquiry through an interview of experienced actors within the unit of analysis (see Table 3), and the resultant compound list is validated and refined through questionnaire. Further refinement takes place by observing projects carried out in the unit of analysis, through which additional barriers not seen in the literature or in the group interview have been identified. Some of these barriers can be found documented in the management of change literature discussed in 2.4.2.

Table 7 below shows how the list of barriers has evolved through this enquiry. The first column shows the barriers from literature, the second column shows the barriers from the group interview and third column shows the additional barriers from observation (with references to the change management literature if applicable).

Table 7 - Developing a list of barriers

Barriers from Energy Efficiency Literature *(See 2.2 Table 1)*	Barriers from the Group Interview *(See 4.3 Table 3)*	Additional Observed Barriers *(See context in 5.1)*
Heterogeneity (L)	Inappropriate Equipment (Lack of access to appropriate equipment) (H/L)	No sense of urgency (Kotter 1996)
Hidden Costs (H/L)	Inadequate Resourcing (Used elsewhere/no dedicated resource) (H/L)	Limited training (Turesky 2010)
Lack of access to capital	Unclear Objectives (L)	Lack of accountability (Turesky 2010)
Risk aversion	Lack of Structure	Not a priority
Split incentives (L)	Lack of process (& energy) knowledge	Unclear who owns what
Principal-agent problems	Complexity of process	
Imperfect information (Incomplete information)	Reliance on Third Parties (H/L)	
Adverse Selection	Inability to Simulate (L)	
Bounded rationality (Lack of understanding) (N/L)	Fear of Impacting Product Quality	
Form of information (L)	Fear of Impacting Health & Safety	
Source of information (N/L)	Lack of Engagement	
Values		
Culture		
Lack of power (N/L)		
Inertia		
Key - Likelihood of the existence of barriers from 4.4		
Highly Likely: (H/L)	Likely: (L)	Not likely: (N/L)

The progression from Literature Review to Interview to Observation can be seen moving across the columns from left to right. The first two columns also show the findings from the questionnaire, with the key barriers highlighted in orange, other important barriers highlighted in yellow, and barriers which were thought not to be important highlighted in grey.

By taking the case studies above as a good representation of the breadth of barriers experienced within the unit of analysis, 11 barriers can be eliminated from the above table, reducing the total from 31 to 20. This results in the list of barriers given at the start of this section (see Table 6). The letters shown in the table correspond to the letter given to the barrier in the case study in sections 5.1.1 to 5.1.3.

What the case studies show is that these barriers don't just exist as independent entities but are, to a greater or lesser degree, connected with each other.

5.4. INTERRELATIONSHIP OF BARRIERS

The case studies presented above in section 5.1 describe each of the barriers listed in 5.2 contextually, showing when and where the barriers occurred and what impact each barrier had on the project. By looking closely at the case studies it can be seen that the impact of some barriers is to cause further barriers to exist - that is, there is a *causal relationship* between those barriers.

For example, in 5.1.1 the barrier of *no clear owner* was found to exist for the energy aspects of the process. This is shown to lead to two other barriers of *split incentives* and *principal-agent problems*. (See Figure 13 below.)

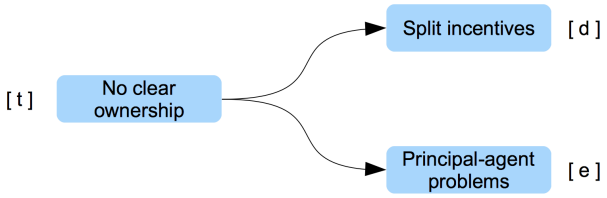

Figure 13 - Lack of ownership as a cause of other barriers

Causality is also shown to flow in the other direction too, with some barriers shown as being caused by other barriers. For example, in 5.1.1 the barrier of a *lack of information* on the process is shown to be caused by a *lack of appropriate equipment* for collecting that information and is also due to the *complexity* of the process. (See Figure 14 below.)

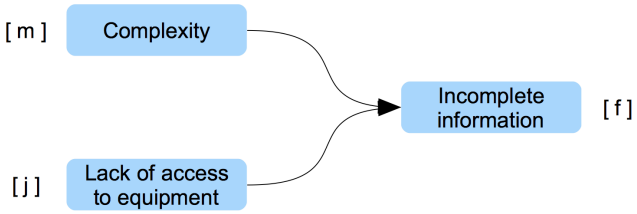

Figure 14 - Lack of information as an effect of other barriers

Thus it is clear that relationships exist between the barriers, with some barriers causing other barriers. By looking through the case studies given above, and through the other data collected throughout the enquiry, causal links between all the barriers can be demonstrated. Cognitive maps for each case study showing these causal links have been produced and can be seen in the Appendices B-D. By combining these together, a compound cognitive map can be created showing causality between barriers across the unit of analysis. The result is shown in Figure 15 below.

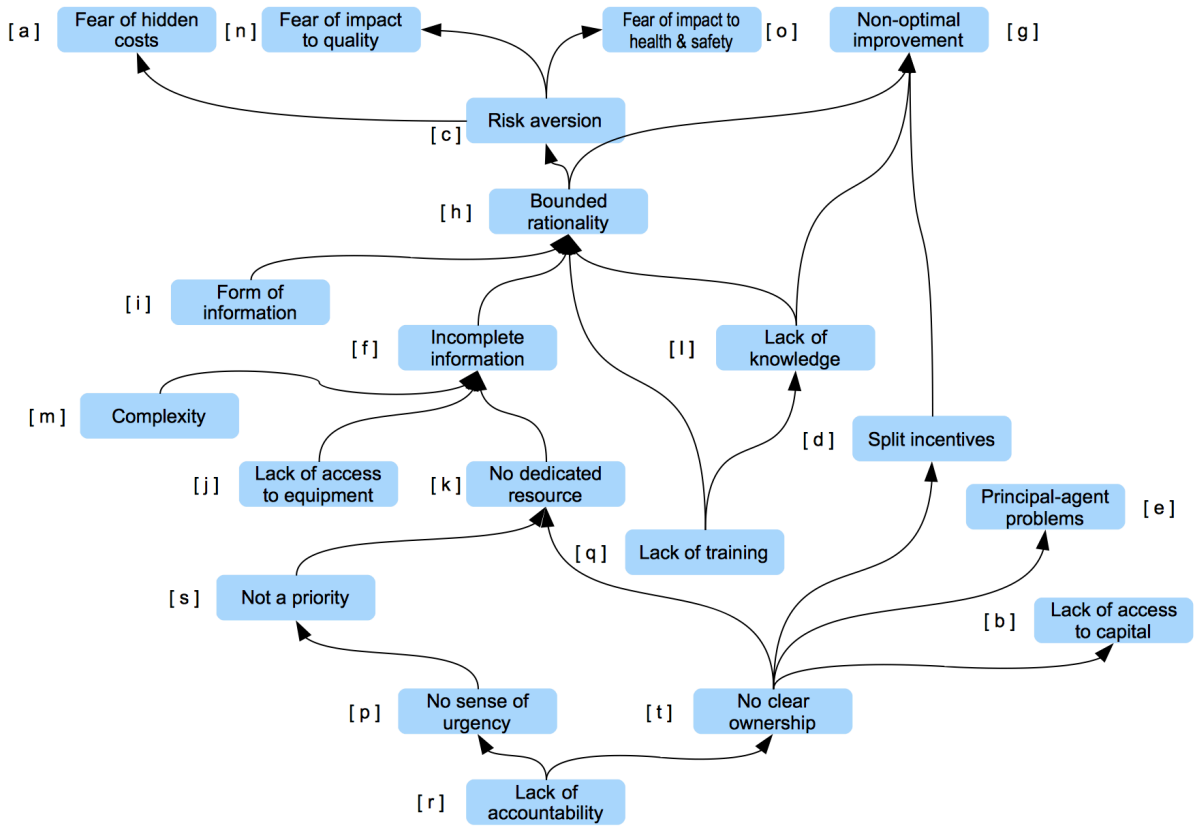

Figure 15 – Cognitive map of the barriers

This causal flow between barriers is important as the effect of overcoming specific individual barriers can be estimated. Causality implies that if we remove a *cause* then the *effects* will diminish or disappear.

For example, in 5.1.2 above the Maintenance function had access to good quality information about the process (*incomplete information* barrier removed) and had a good understanding of the process (*lack of knowledge* barrier removed). This overcame the barrier of *bounded rationality* since good quality decisions could be made - which in turn meant that the proposal was high quality (*non-optimal improvement* barrier removed) and that risks were well-understood (*risk aversion* barrier removed).

However, when the barrier of *incomplete information* was removed another barrier became apparent - that there was *no dedicated resource* in the Maintenance function for carrying out the work because of the more important work being carried out on the shutdown (activity still *not a priority*). Thus the project was still delayed.

By understanding the causal flow, a picture of which barriers are the most significant can be built – that is, we can start to see which barriers provide a **root cause** for the other barriers. By identifying these key barriers interventions, can be designed to tackle those barriers alone resulting in multiple barriers being overcome.

5.5. KEY BARRIERS

The diagram above shows causality flowing upwards in a kind of tree. At the end of the branches are **outcomes**, or barriers not causing any further barriers. Some barriers can stop execution permanently or temporarily e.g. *fear of impact to quality*, *lack of access to capital*. Other barriers can mean that the result of the project is not as good as it could have been, i.e. a *non-optimal solution* is selected.

At the bottom of the tree are the **roots**, the barriers which cause the other barriers to exist. The root causes are all related to **accountability and ownership** and are shown in Table 8 below illustrated with examples.

Table 8 - Key barriers with illustrations

Barrier	Example	Data Sources
Lack of Accountability	The site Energy Manager is responsible for reducing the site energy consumption but only has authority to act within a Facilities domain – that is, by improving facilities and services, such as buildings and switchgear. He is not empowered to act within a Manufacturing Operations perimeter. No-one is responsible for reducing energy demand.	*Journal; Project documentation (weekly reporting, emails); organisational structure; job descriptions/objectives.*
No Clear Ownership	Many improvements are identified but then delayed due to a lack of funding to carry out the works. This is because neither Facilities nor Manufacturing Operations can often agree whether the improvement is inside their perimeter: typically, Facilities claim that it is a manufacturing process improvement, and Operations claim that any benefit would be realised by Facilities. Both are correct, but neither will commit resources to achieve the improvement and own the improvement.	*Journal; Project documentation (weekly reporting, emails); organisational structure.*

These barriers have been identified as root causes since they are not the effect of other causes (there are no arrows going into them in Figure 15 above) and because they cause multiple other barriers (there are many arrows coming from them in Figure 15 above). These barriers are what hold all the other barriers in place. If these barriers ceased to exist then the other barriers may also cease to exist, or at least diminish in terms of their impact.

By looking at the tree it can be seen that the barriers at the top (i.e. the outcomes) are generally **operational** in nature; they are the barriers which would be experienced by people carrying out the activities. To some extent this ties in with the results from the questionnaire. *Hidden costs*, for example, was one of the most widely perceived barriers (with only three of the nine questioned not perceiving this as a barrier) and it can be seen at the top of the tree.

The barriers at the bottom on the other hand are more **organisational** or strategic in nature. These barriers are not readily perceived by the actors within the unit of analysis since they don't directly affect them; it is the effects of the organisational barriers which they perceive. Thus (with the exception of *inadequate resourcing*) there is little evidence for them in the data collected on the perceptions of individuals through the interview and questionnaire. For the key barriers in Table 8 above it can be seen that the primary source of data is through the research journal (direct observation) and the notes contained therein pointing to the more quantitative company records.

Since the barriers are organisational then the interventions to overcome these will also need to be applied at an organisational level. These are discussed in the following section.

5.6. OVERCOMING BARRIERS

A number of interventions were applied to overcome the key barriers identified in the questionnaire (see 4.4.1). The researcher also applied some interventions when barriers were encountered during project execution (see 4.4.2). Some natural inventions were also observed during project execution (see 5.1.2). These approaches aimed to overcome individual barriers with individual interventions. This approach can lead to some success even eliminating some barriers, such as in the case of the barrier of *inadequate equipment*, which disappeared after equipment was purchased. For other barriers interventions designed and applied in such a way simply mean that those interventions will always need to be applied. This approach treats the *symptoms* of the problem without dealing with the *cause*.

By viewing barriers as a causal network as described in 5.3 it can be seen that a small number of barriers may hold the other barriers in place. Thus by designing and applying interventions to overcome these barriers at a strategic organisational level many of the other barriers may cease to exist.

It is proposed that by developing interventions to overcome the key barriers listed in 5.4 that all the barriers to energy reduction within the unit of analysis may be diminished or removed, answering RQ2.

Table 9 below lists possible interventions.

Table 9 - Overcoming the key barriers

Barrier	Possible Intervention
Lack of Accountability	Manufacturing Operations will be given objectives for reducing the energy consumption of manufacturing processes.
No Clear Ownership	Manufacturing Operations will nominate a focal point responsible for energy reduction activities within the unit of analysis. The focal point will work closely with Facilities. Funding rules will be developed for energy reduction projects in a manufacturing perimeter.

The first intervention relates to setting **objectives** on the people who are in the best position to influence the energy consumption of manufacturing equipment. An objective is a means by which a person or function can be held to account and is used to drive activities. The change management literature is very clear on the importance of objectives and how they can promote action (e.g. Kotter, 1996). By setting objectives it is expected that the barrier of a *lack of accountability* will disappear. Good objectives are time-bound and thus the barrier of *no sense of urgency* should also be overcome. This in turn will to some degree influence the *priority* of the activity and may also lead to more *resources* being available. Thus the effect of applying this intervention will cascade up the tree and remove or diminish the effect of the other barriers.

Setting objectives, or suggesting actions, will only have an effect if there is someone available to **own** the actions and be measured against the objectives. Thus by creating a focal point with the power to act in the unit of analysis the barrier of *no clear ownership* will be removed. As with the intervention above, the effect of this will cascade up the tree. The *principal-agent problems* experienced from situations with unclear ownership and the *split incentives* to act will be

diminished, provided that the focal point also collaborates with other functions which have a vested interest in the outcome, particularly Facilities.

The power of the focal point is important as it will impact the extent to which barriers further up the tree will be impacted. If the focal point has staff working for him/her then the barrier of a *lack of resources* could be overcome. If the focal point has budgetary authority then the barrier of *access to capital* can be overcome, provided that appropriate funding rules are in place to support activities related to energy reduction.

These interventions will form the basis of recommendations to the manufacturing organisation on how to develop a strategy for energy reduction in manufacturing and will be developed further through further work in practice.

Clearly there are some barriers that these interventions will not overcome – such as the *complexity* of the manufacturing process, a *lack of training* or the way in which activities are communicated (*form of information*). These may require further interventions to be developed so that the effect of other barriers further up the tree can be diminished.

All the interventions discussed here are targeted at an *organisational* level. The purpose of the interventions is to bring about structural change to the unit of analysis or the manufacturing organisation and so support the individual actors at an operational level. The interventions should cause the barriers to cease to exist and thus the individual actors will not perceive those barriers. However, although the survey showed that the personal *values* with respect to energy reduction was not a barrier, there may still be individuals within the unit of analysis who are not fully committed to the activity and may act as barriers themselves. Organisational interventions can only go so far when trying to influence the behaviours of individuals and so even when the interventions are applied it may be necessary from time to time to also develop further specific interventions targeting the actor-barriers within the organisation.

5.7. SUMMARY

The barriers collected from the unit of analysis have been analysed by looking at specific projects. Through these projects new barriers were found and other barriers could be discounted. **This led to a list of barriers evident in the unit of analysis answering RQ1.**

The rich descriptions from the specific projects showed that there was a causal relationship between the barriers. A cognitive map of the barriers has been drawn which identified a number of key barriers holding the other barriers in place. **It was proposed that designing suitable interventions to overcome these barriers alone would remove or diminish the other barriers, thus providing an answer to RQ2.**

6. DISCUSSION & CONCLUSION

6.1. IDENTIFYING BARRIERS

The key barriers to energy reduction in manufacturing were found to be a **lack of accountability** (no one is responsible for energy reduction in a manufacturing perimeter) and **no clear ownership** (the boundaries of that perimeter are often unclear). The complete list of barriers (from Table 6) is also shown below.

- Hidden costs
- Lack of access to capital
- Risk aversion
- Split incentives
- Principal-agent problems
- Imperfect/incomplete information
- Adverse selection/Non-optimal improvement
- Bounded rationality/Lack of understanding
- Form of information
- Inappropriate/Lack of access to equipment
- Inadequate resourcing
- Lack of process knowledge/understanding
- Complexity of process
- Fear of impacting product quality
- Fear of impacting health and safety
- No sense of urgency
- Limited training
- Lack of accountability
- Not a priority
- Unclear who owns what

This list of barriers has been refined over the course of the enquiry. An initial list of barriers from literature was presented (2.2.3, Table 1) which was added to by collecting data through interview (4.2, Table 3). This combined list was then reviewed through a questionnaire to determine the perception of the barriers within the unit of analysis (4.3, Table 4). By observing energy reduction activities within the unit of analysis, presented as a number of case studies (see 5.1), the list of barriers was further refined to produce this list.

The barriers are based on an investigation in a single unit of analysis, which means that inferences as to its wider applicability should be treated with caution. Although the results of the research could be applied more widely, the research shows that these barriers exist in this part of the organisation alone. Additional research must be carried out outside the unit of analysis to further validate the findings. This could include following a similar methodology in other parts of the manufacturing facility or in other facilities operated by the manufacturing organisation. It could also include conducting a similar enquiry in another manufacturing organisation.

The list of barriers describes the unit of analysis well. The barriers are grounded in literature, evidenced by observations made of multiple cases and, where applicable, triangulated using relevant company documents - thus the barriers can be considered an accurate reflection of reality inside the unit of analysis. This provides new knowledge on the subject of energy reduction in manufacturing, something which is absent from the literature.

This list of barriers provides an answer for the first research question: *"What are the organisational and management barriers to the application of energy reduction initiatives?"*

Additionally, the barriers have been linked causally. The literature describes a number of generic barriers, both in terms of barriers to implementation and barriers to energy efficiency. These barriers are at worst a simple list and at best a categorised list. By analysing the rich data contained within the multiple case studies, this research has identified causal links between the barriers. This too is new knowledge, and also provides a contribution to practice. By understanding how barriers are linked - and what the root cause of a number of barriers is - interventions can be designed and implemented to overcome a smaller number of barriers, thus chopping down the tree of barriers at the root rather than simply pruning its branches.

6.2. OVERCOMING BARRIERS

During the enquiry a number of interventions were applied to overcome barriers which were identified as being important from the questionnaire (see 4.4.1, Table 5). These interventions were found to have some limited impact on overcoming barriers. For example, providing energy monitoring equipment overcame the barrier of a *lack of access to equipment*. (Compare 5.1.1 and 5.1.2.) However when this barrier was removed another barrier took its place; although the equipment was available there was *no resource available* for using it (see 5.1.2). Thus from this and other examples two important facts were learnt: tackling individual barriers based on perceived importance had limited impact, and barriers were linked causally.

By analysing the case studies in 5.1.1 to 5.1.3 a cognitive map was produced which showed the interrelationship between the barriers observed (see 5.4 Figure 15, reproduced in Figure 16 below). On the edges of the diagram are barriers which are mainly effects of other barriers ("outcomes" in 5.4), whilst at the bottom of the diagram are barriers that mainly cause other barriers. ("roots" in 5.4). The root barriers tend not to be perceived by the actors within the unit of analysis, since they exist at an organisational level which is far removed from daily operations. However it is these barriers which hold all the other barriers in place.
Here the key barriers can be seen at the bottom of the tree acting as a cause to the other

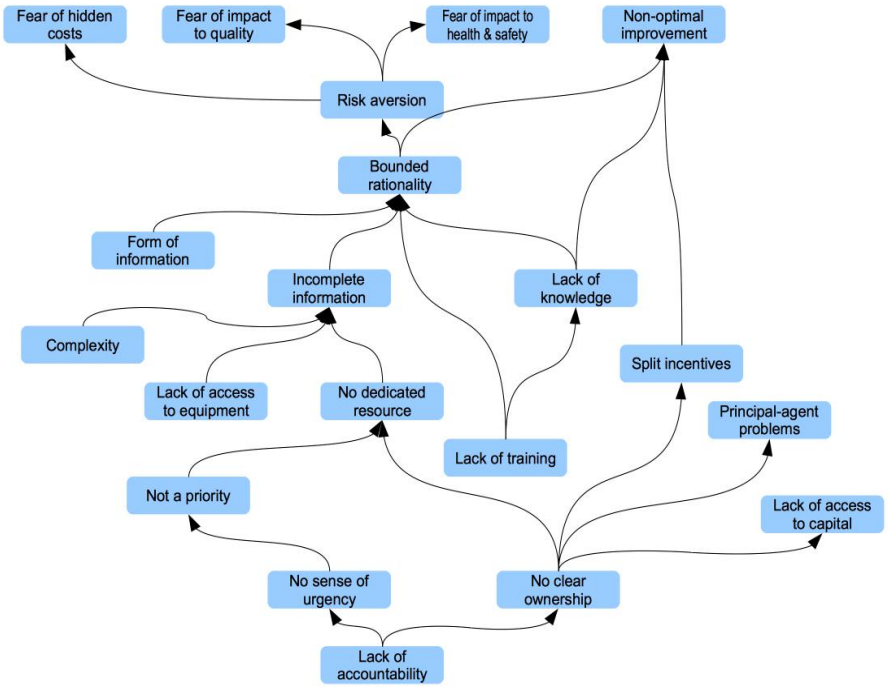

Figure 16 – Cognitive map of the barriers (from Figure 15)

barriers. It is proposed that designing interventions to overcome these barriers may diminish the effect or remove the other barriers which are perceived by the actors within the unit of analysis.

A number of organisational proposals are given in 5.5 (Table 9), which are now being applied within the unit of analysis and more broadly across the manufacturing organisation. These include setting energy reduction **objectives** for the Manufacturing Operations function, and nominating a **focal point responsible** for carrying out activities to meet these objectives, with appropriate **resourcing** and **funding**.

This provides an answer for the second research question, ***"What interventions or organisational changes can be made to overcome these barriers?"*** Further work will need to be carried out to determine the effectiveness of these proposals.

6.3. CONTRIBUTION

6.3.1. Contribution to Knowledge

This research contributes to knowledge by answering the original research questions posed and by closing the gaps identified from the literature review. The specific contribution can be summarised as follows.

- *A list of barriers has been developed which describe the barriers to energy reduction in a manufacturing environment, specifically those in the unit of analysis. This answers RQ1 and closes Gap 1.*
- *Causality between the barriers has been identified, leading to the new knowledge relating to key barriers. This has provided a proposal for answering RQ2 and closes Gap 2.*

6.3.2. List of Publications

As a traditional measure of the contribution to knowledge, the following list details the published material which is linked to this research.

The following publications were produced by the researcher as part of this research.

Lunt, P., & Levers, A. (2011). *Reducing Energy Use in Aircraft Component Manufacture - Applying Best Practice in Sustainable Manufacturing.*

Lunt, P., & Ball, P. (2012). *Barriers to energy reduction in manufacturing.*

Additionally, the researcher provided contribution to the following publications as author.

Ball, P., et al. (2011). *Modelling energy flows across buildings, facilities and manufacturing operations.*

Ball, P., et al. (2012). *Modeling buildings, facilities and manufacturing operations to reduce energy consumption.*

6.3.3. Contribution to Practice

In addition to the academic contribution, this research has also contributed to **practice**. As action research, the unit of analysis has been improved through the course of the research by the application and development of interventions. The successful execution of a number of projects can also be attributed to this. Over the course of the research a total in excess of 2.5 GWh of energy has been saved in the unit of analysis through the projects. Had the activity been purely practice-driven (as opposed to being also research-driven) it is likely that the savings would be less than this. Whether the barriers would be overcome or not without this research focus is moot but it is unlikely that learning would have been carried over from project to project.

The strategy for overcoming the barriers through applying interventions on the root causes is also a significant contribution to practice. The proposed interventions provide practical guidance on organisational changes which is actionable within the unit of analysis. The guidance has been embodied in the industrial energy roadmap of the manufacturing organisation.
From a practical point of view, the research is also highly accessible and has been carried out and documented in a such a way that learning can be cascaded internally within the

manufacturing organisation and also has the potential for being testing in other companies and in other industry sectors.

6.4. RESEARCH QUALITY

In 3.4.3 the idea was introduced that actions should be taken during the course of the enquiry to ensure that the output of the enquiry is of the highest possibly quality. These actions can take the form of three checks: **replicability**, **reliability** and **validity**.

To ensure **replicability** the researcher must document the way in which the enquiry was conducted in a sufficient level of detail to allow another researcher to carry out the enquiry in the same way – that is, to allow the work to be replicated. The methodology used is clearly outlined in Chapter 3 and the way in which the methodology was applied to collect data is given in Chapter 4, including which approaches and instruments were used to collect the data.

Replicability may be a difficult criterion to satisfy for an action-based approach such as conducted in this enquiry, where each phase of work is highly dependent on the preceding phases, and also where the researcher has a vested interest in positive outcomes. Thus the researcher must seek to be as reflective as possible and keep detailed records of any actions carried out. This has been done to considerable degree in Chapter 4, although, as would always be the case, more data could have been collected and documented.

The way in which the data is presented does make the approach more accessible to other researchers, or indeed to other practitioners. Indeed, similar analysis is already planned across a number of other similar units of analysis based on the methodology outlined in this document.

The extent to which the research can be considered believable or trustworthy is a measure of **reliability**. To some extent this means that the researcher should employ appropriate methods and means of collecting and analysing data, as documented above. The action research strategy was deemed the most appropriate and is aligned to the epistemology and ontology of the research. It is also the most obvious strategy for a practitioner-researcher to adopt. The ways of collecting and analysing data are consistent with this strategy and are not applied in novel or unusual ways.

There must be a logical flow to the research such that a reader can understand why the researcher did things in the way that s/he did (as described above), so that when the conclusions are presented they should appear obvious. The causality flowing through the research is a measure of its **validity**. Using multiple data sources increases this validity since the conclusions will appear more obvious. In this research the primary source of data was through direct observations made by the researcher. This was grounded on literature and on data collected on the opinions of actors.

Although not referred to explicitly in this document, company documents were used by the researcher to provide additional triangulation for the recorded observations. Better documentation of this would improve the confidence in the research. Additionally the conclusions drawn in this research are presented as a direct result of the analysis by the researcher. These conclusions could have been further validated by seeking the opinions of the actors within the unit of analysis again, as was done at the start of the enquiry, thus closing the loop.

The validity will clearly also be increased by working through more cycles of the action research approach and by expanding the scope of the initial enquiry to work across a broader range of processes in the manufacturing facility, across a number of different facilities within the organisation and indeed across different companies and different sectors. This and other examples of how this work can be advanced are given in the following section.

6.5. FURTHER WORK

The conclusions drawn from this enquiry are based on data collected from within the unit of analysis and thus are only applicable to the unit of analysis. Additional work should be carried out to determine the scope of applicability of the conclusions in two dimensions - by expanding the unit of analysis to cover a larger part of the manufacturing organisation and by carrying out the same enquiry in a different organisation outside and unrelated to the unit of analysis.

In terms of expanding the scope of the current unit of analysis, this is something which is currently being explored by the manufacturing organisation. The conclusions drawn and interventions proposed will be tested by inclusion in an energy reduction strategy and supporting methodology which is being deployed across the European operations of the manufacturing organisation. By continuing to implement improvements in a similar fashion as has been done in this research - in an action-based and reflective approach - it is expected that conclusions drawn will be validated or improved upon.

6.6. CONCLUSIONS

- A list of barriers has been developed which describe the barriers to energy reduction in the unit of analysis (see 6.1).
- Causality has been identified between the barriers (see 6.2).
- The root causes of barriers within the unit of analysis can be seen to be
    - a lack of accountability; and
    - no clear ownership.
- An approach to overcoming barriers by identifying interventions for key barriers has been shown, including
    - setting energy reduction objectives for Manufacturing Operations; and
    - nominating and empowering a focal point in Manufacturing Operations responsible for carrying out activities to meet these objectives.
- Further work is required to test that the causality demonstrated through the case studies can be observed more widely, both within the unit of analysis and elsewhere.

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Attitudes to Energy Saving Questionnaire ***Date*** _____

Name _____ ***Function*** _____

Please indicate to what extent you agree or disagree with the following statements by circling the appropriate number to the right of each statement.

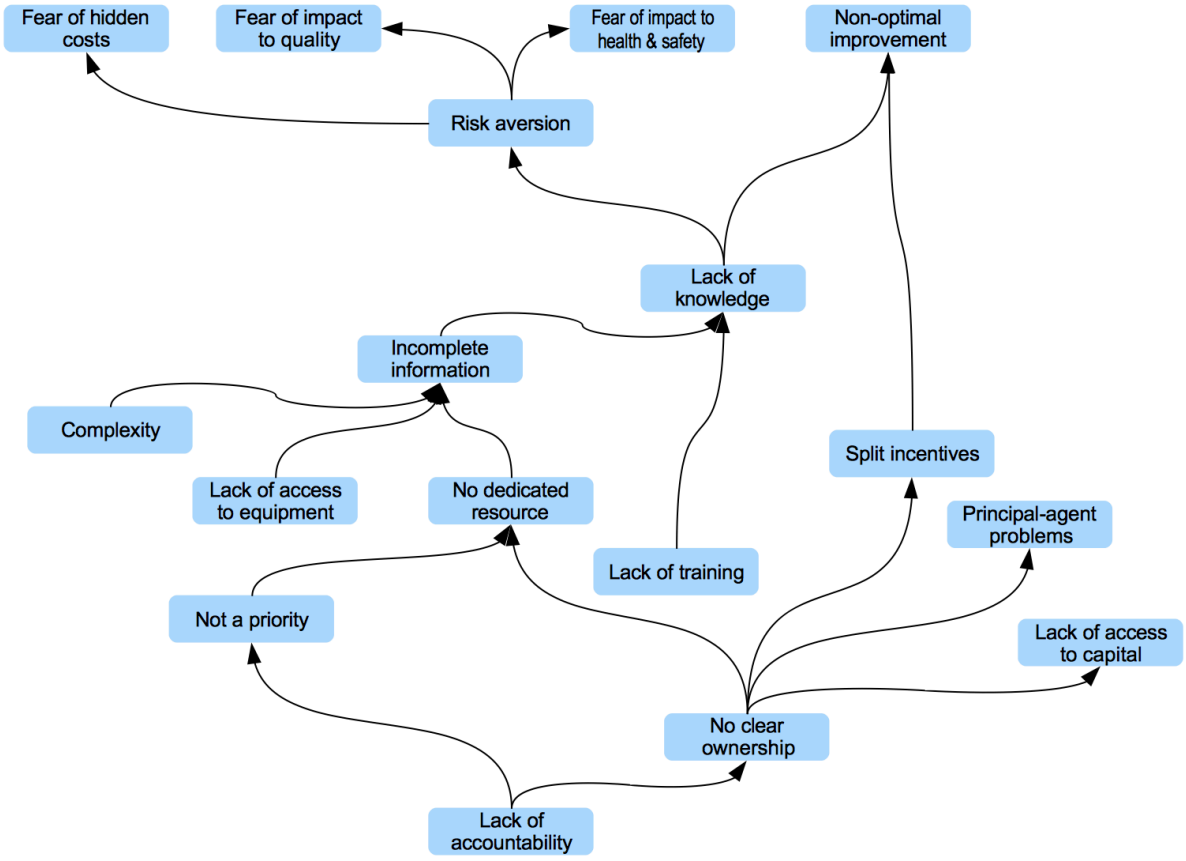
		Always Disagree	Mostly Disagree	Usually Disagree	Usually Agree	Mostly Agree	Always Agree
1)	"Reducing energy reduces the cost of production"	1	2	3	4	5	6
2)	"Rising energy prices are a real concern"	1	2	3	4	5	6
3)	"Saving energy makes us more competitive"	1	2	3	4	5	6
4)	"Suppliers can help us to be more energy efficient"	1	2	3	4	5	6
5)	"It is important for the company I work in to be 'green'"	1	2	3	4	5	6
6)	"Saving energy is important to me"	1	2	3	4	5	6
7)	"Saving energy is good for my personal development"	1	2	3	4	5	6
8)	"A good company should have a long term energy strategy"	1	2	3	4	5	6
9)	"An environmental management system helps save energy"	1	2	3	4	5	6
10)	"Saving energy improves working conditions"	1	2	3	4	5	6
11)	"Airbus requires unique solutions for reducing energy"	1	2	3	4	5	6
12)	"It is not possible to fully predict the total cost of implementing energy saving projects"	1	2	3	4	5	6
13)	"There aren't enough funds for energy saving projects"	1	2	3	4	5	6
14)	"There are too many risks involved in implementing energy saving projects"	1	2	3	4	5	6
15)	"If I reduce energy use someone else will get the benefit"	1	2	3	4	5	6
16)	"It is the responsibility of another function to reduce energy in my area"	1	2	3	4	5	6
17)	"I don't know enough about energy saving to be able to reduce energy in my area"	1	2	3	4	5	6
18)	"Other factors (e.g. cost) are more important than energy efficiency when making investments"	1	2	3	4	5	6

		Always Disagree	Mostly Disagree	Usually Disagree	Usually Agree	Mostly Agree	Always Agree
19)	"As far as I know, we're already as energy efficient as we can be"	1	2	3	4	5	6
20)	"The information on energy reduction is unclear"	1	2	3	4	5	6
21)	"The people who promote energy saving i[redacted] are not completely credible"	1	2	3	4	5	6
22)	"Saving energy isn't important to me"	1	2	3	4	5	6
23)	"Saving energy isn't important t[redacted]"	1	2	3	4	5	6
24)	"I can't affect how much energy we use in manufacturing"	1	2	3	4	5	6
25)	"It would be too difficult to change our processes to be more energy efficient"	1	2	3	4	5	6
26)	"I have access to all the equipment I think is required for saving energy in my area"	1	2	3	4	5	6
27)	"I have been allocated sufficient time to work on energy saving projects"	1	2	3	4	5	6
28)	"In terms of energy projects, I understand what needs to be done, how it will be done and by when"	1	2	3	4	5	6
29)	"There is a dedicated team I can turn to for guidance on energy reduction"	1	2	3	4	5	6
30)	"I completely understand the processes in my area"	1	2	3	4	5	6
31)	"I completely understand how the different processes in my area interact"	1	2	3	4	5	6
32)	"I have instant access to all the help I need for saving energy in my area"	1	2	3	4	5	6
33)	"I can accurately predict the impact any improvement will have in my area"	1	2	3	4	5	6
34)	"It is possible to mitigate any risks to quality before implementing an energy saving project"	1	2	3	4	5	6
35)	"It is possible to mitigate any risks to health & saftey before implementing an energy saving project"	1	2	3	4	5	6
36)	"I feel involved with energy saving activities"	1	2	3	4	5	6

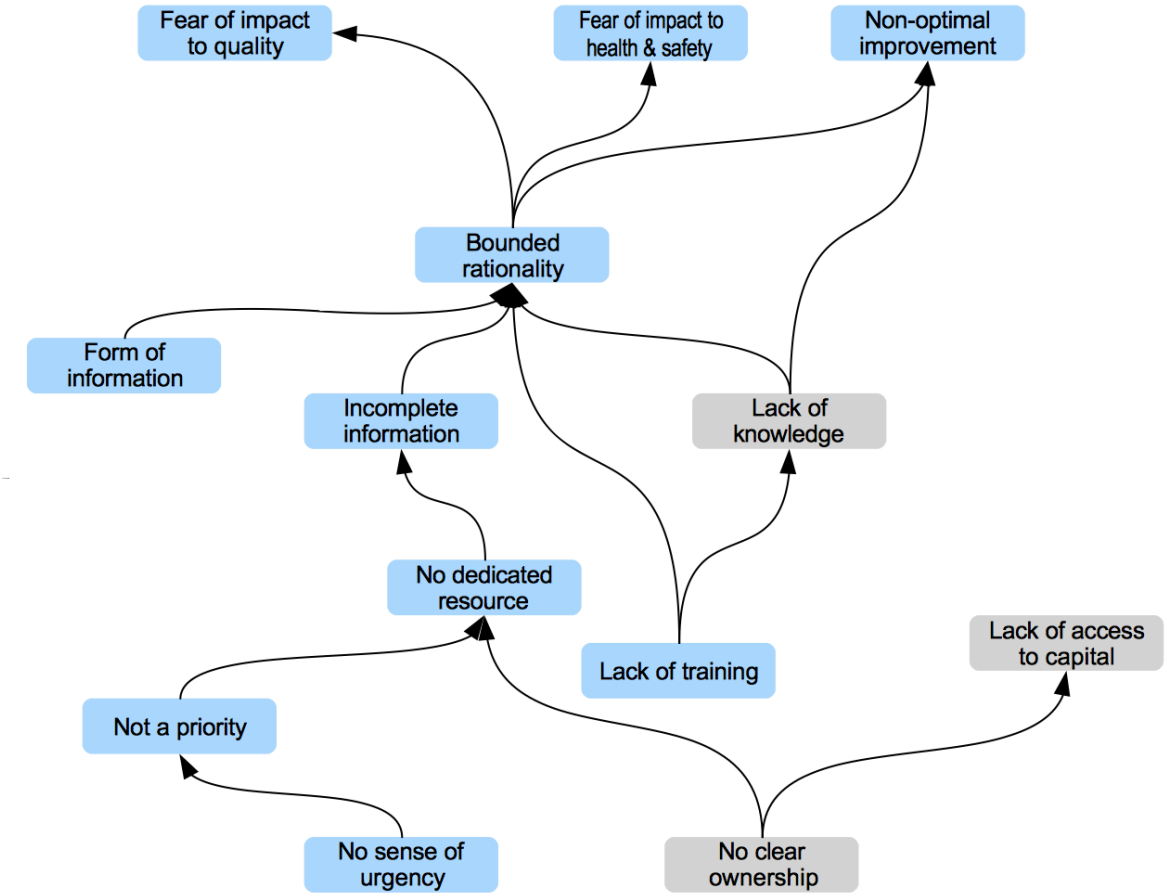
What do you believe is the most important reason to save energy i[redacted]?

What do you believe is the most significant obstacle to implementing energy saving projects i[redacted]?

APPENDIX B – Barriers from 5.1.1



APPENDIX C – Barriers from 5.1.2



APPENDIX D – Barriers from 5.1.3